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Structure and Stratigraphy of the Limestones and Dolomites of Dauphin County, Pennsylvania

David B. MacLachlan

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BULLETIN G 44

Structure and Stratigraphy of the Limestones and Dolomites of Dauphin County, Pennsylvania

by David B. MacLachlan
Pa. Geological Survey

PENNSYLVANIA GEOLOGICAL SURVEY
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STRUCTURE AND STRATIGRAPHY OF THE LIMESTONES AND DOLOMITES OF DAUPHIN COUNTY, PENNSYLVANIA

by

David B. MacLachlan

ABSTRACT

Middle Cambrian to Middle Ordovician carbonate rocks with associated younger Ordovician shales underlie the Great Valley through southern Dauphin County and represent the only significant carbonate development in the county. In the western part carbonates outcrop in two distinct belts. The northern belt begins west of Hummelstown and opens westward into the main carbonate area of the Cumberland Valley. The southern belt extends only a few miles west of the county but merges eastward into the Lebanon Valley. The two belts are found to have distinct though related stratigraphic sequences formed in somewhat different depositional environments which owe their present proximity to tectonic superposition. The Cumberland Valley sequence shows northwesterly tectonic transport by overturned folds and steep thrusts, but it is essentially upright and apparently autochthonous. The Lebanon Valley sequence is regionally inverted, and the structure is dominated by thrust faults ranging upward to minimum probable displacements of several miles. The base (stratigraphic top) of the inverted sequence is composed of shales which, in western Dauphin County, clearly override the Cumberland Valley carbonates on a thrust of large but uncertain displacement. This thrust is in the position of a major "Taconic" thrust proposed by G. W. Stose, but the upper plate shales are here recognized as in depositional continuity and transported with the Lebanon Valley carbonates. The thrusting and folding of the lower plate are not older than late Acadian age, and synorogenic deposition and sliding is invoked to explain features of the shale stratigraphy which indicate Taconic age thrusting. The eastward continuation of the thrust is uncertain, owing to its development within a shale terrane which is inadequately known. Structures of the Lebanon Valley carbonates indicate that major thrusting extends at least to the Schuylkill River vicinity and underlies a nappe of Alpine style and proportions.

Stratigraphic discussion of the two carbonate sequences includes units not exposed in Dauphin County to fully develop the stratigraphic differences which support the inference of major thrusting. Most units conform in age and extent to prior usage, but this study suggests revision of some stratigraphic details. Previous suggestions that the uppermost part of the Beekmantown Group in this area might be Chazyan age are reaffirmed, and modification of Hobson's correlation of Great Valley Beekmantown subdivisions is indicated. Type sections of the Myerstown and Hershey Formations lie in the study area, and mapping to the type sections requires establishment of a supplementary reference section for the Myerstown and redefinition of the Hershey to conform to previous mapping of these units in Lebanon County. Hershey and Myerstown are not considered a desirable replacement for the term Jacksonburg Formation in the cement district. Contrary to prior reports, clear lateral gradation between the St. Paul Group and the Annville For-

mation is not recognized, and the Annville outcrop shown in the northern be on the State Geologic Map is erroneous.

Available chemical data are summarized to support correlations and assist evalu tion of potential uses of the various units. The Annville Limestone is found to r tain identity as a high-calcium unit throughout its Dauphin County exposur and substantial undeveloped reserves remain. The upper Ontelaunee Formation a pears to offer an unexploited potential for good quality dolomite. Several oth formations contain large reserves of stone suitable for high quality aggregate an similar uses but are too impure or variable in composition for uses critically d pendent on the rock chemistry.

INTRODUCTION

GENERAL REMARKS

Limestones and dolomites have long been the most important miner product of Dauphin County, but imperfectly understood stratigraphy an structural complexity have complicated exploitation. The present pap gives the results of detailed geologic mapping at a scale of 1:24,000 o aerial photographs and recent topographic maps applying stratigraph information largely obtained in the last decade. The results of this stud not only provide a clearer picture of the distribution of units of particul interest to quarrymen, but also reveal some aspects of the structure this part of the Appalachian Mountain system of considerable theoretic interest.

Adequate treatment of the problems presented by the structural com plexities of this area has resulted in a more voluminous report than w anticipated at the onset of this project. It contains some sections that ma be of little interest to those primarily concerned with limestone extractio but solution of the theoretical problems was essential to understandi the highly practical question of the distribution of economic units. Th mapping performed on this project will ultimately be included in geolog quadrangle maps of the Geologic Atlas series. This unified report for t limestone area, however, permits a more prompt and comprehensive trea ment of the economic potential and a more coherent presentation of t significant geologic findings.

While it is hoped that this report will be useful to all persons intereste in limestones and dolomites as a mineral commodity and those more ge erally interested in the geology of the area, it is of necessity quite technica The complexity of the area studied makes it impossible to discuss it ad quately without frequent recourse to geological terms which may be u familiar to the layman or have meanings more specialized than their u in common speech. Readers without geologic training who are intereste in prospecting for or producing limestone in this area are advised to co sult a professional geologist.

LOCATION

Two major outcrop areas of carbonate rock occur in Dauphin County (Figure 1 and Plate 1). The larger extends from the Lebanon County line in the vicinity of Palmyra Borough on the east across the county to Steelton Borough on the west. The 3.4 mile width outcrop belt at the Lebanon County line is fairly representative of the crop width of the limestone sequence of the Lebanon Valley in western Lebanon County. It is reduced abruptly to less than half that width in the vicinity of Hershey though it retains the west-southwest trend of the Lebanon Valley to Hummelstown. At Hummelstown it turns southwest to the latitude of Steelton where it joins again to about ½ mile and turns nearly due west. This belt continues only a few miles west of Steelton and terminates at Bowmansdale in Cumberland County.

The smaller crop area begins about 1.9 miles due west of Hummelstown square where it comes within less than a mile of the other. It extends just slightly south of west through the western half of Dauphin County reaching the Susquehanna River in the southern part of Harrisburg. It generally widens gradually, though irregularly, to the west and then opens more rapidly into the main limestone sequence of the Cumberland Valley at the western edge of the County.

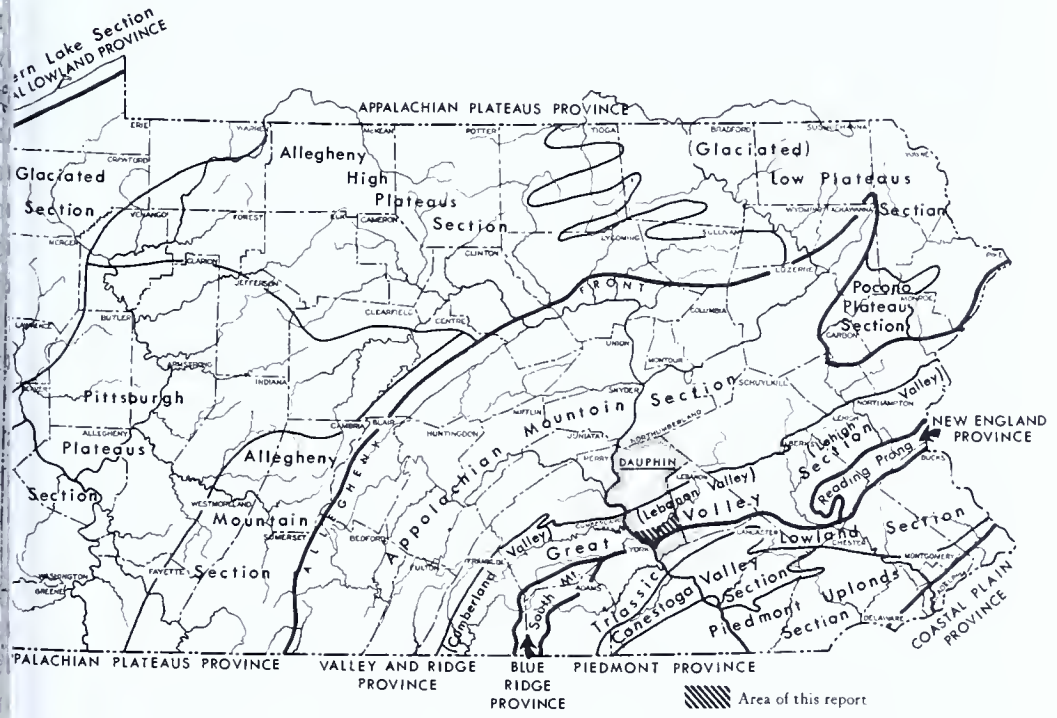


Figure 1. Physiographic provinces of Pennsylvania and location of area of this report.

The outcrop areas include parts of the Harrisburg East, Hummelstown Middletown, Palmyra, and Steelton 7½-minute topographic quadrangles The Reading Railroad and highway routes U.S. 322 and U.S. 422 follow the limestone outcrop east from Harrisburg and cross shale into the Lebanon Valley belt in the vicinity of Hummelstown and continue thence eastward on carbonate rocks.

TOPOGRAPHY AND DRAINAGE

As expected of soluble rocks in a humid climate, the limestones and dolomites underlie valleys of low relief. These valleys are crossed by through-flowing streams but are not themselves stream valleys. Indeed so far as there is any systematic pattern to the direction of permanent streams, it is transverse to the limestone valleys. Some smaller streams rising on adjacent shales and sandstones do gradually sink into their beds on reaching the limestone valley, and others start abruptly at large springs but the drainage pattern of the valleys may be said to be integrated in the sense that no area, exclusive of sinkholes, lacks a potential watercourse connecting it to a permanent through-flowing stream. Some of these water courses are more or less well-defined intermittent streams. Many are merely gentle swales, the cultivation of which indicates that only the most transient flow is encountered during intervals of maximum run-off. Together however, they compose a dendritic system, in places controlled to some extent by variations in the bedrock, tributary to the regional stream flow. The large areas lacking permanent streams make it apparent that the bulk of the drainage from the limestone area is subsurface, but subsurface drainage has not developed to the extent that surface drainage lines have disintegrated into a mosaic of systems tributary to major sinks.

The valleys are bounded to both north and south by hills. On the south the Triassic Gettysburg Formation of red sandstone, shale and conglomerate supports hills that rise quite abruptly to as much as five hundred feet above the valley. On the north, and on both sides of the northwestern valley, a complex of mostly argillaceous and somewhat metamorphosed terrigenous clastics assigned to the Martinsburg Formation supports a line of lesser hills which is actually just the frontal scarp of the higher lying and more deeply dissected noncarbonate-floored part of the Great Valley the major valley defined by the Triassic hills to the south and First Mountain to the north (Fig. 1).

ACKNOWLEDGMENTS

It is impractical to thank individually all those who contributed information or cooperated in other ways in the preparation of this report. Some

ersons encountered casually during field work, whose names I never knew, ave been very helpful. The cooperation of all is appreciated.

While the author assumes full responsibility for the interpretations erein and for compilation of the accompanying map (Plate 1), including ny errors that may appear, other members of the staff and cooperating eologists of the Pennsylvania Geological Survey have made significant ontributions to this report. Dr. Carlyle Gray introduced the author to the omplexities of stratigraphy and structure of the Lebanon Valley and gave onsiderable amounts of his time and experience to the early part of this vork. Mr. Alan Geyer has mapped the area of the Annville Limestone uarries between Palmyra and Hershey in great detail. Some data from his ield mapping in the Palmyra quadrangle is also included here. Mr. Sidney Barnes has done mapping in the Cambrian and lowermost Ordovician of he Palmyra and southeast part of the Hummelstown quadrangles. The ontact with the Triassic Gettysburg Formation in these two quadrangles vas mapped by Dr. Dean B. McLaughlin. Dr. James Dyson and Dr. Samuel Root have contributed largely to my understanding of the Cumberland Valley stratigraphy that is essential to this report.

GENERAL GEOLOGIC SETTING

Significant occurrences of carbonate rocks in Dauphin County are confined to the southern part of the county where it is crossed by a major physiographic and geologic subprovince commonly called the Great Valley. The physiographic provinces of Pennsylvania and the location of the area studied are shown in Figure 1. Physiographically this valley is an area of relatively low elevation and low to moderate relief between regions of distinctly higher average elevation and relief that may be traced continuously from southeastern New York to Alabama. Geologically this subprovince is grossly simple in that it shows a remarkable uniformity of general pattern throughout its great length, but it is quite complex in detail. In parts of Berks and Cumberland, and in all of Dauphin and Lebanon Counties the typical cross section of the valley has been modified in a manner to be described subsequently. It is constructive, however, to consider the typical cross section which is generally valid for most of the valley from New York to Alabama.

Throughout its entire length the valley owes its position to the erosion of a thick sequence of Cambrian and Ordovician carbonate rocks and shales bounded on both sides by rocks considerably more resistant to erosion. The typical cross section is stratigraphically simple. On the east a ridge of Precambrian crystalline rocks is unconformably overlain by bedded clastic rocks of Cambrian and in places latest pre-Paleozoic (?) age. The bedded rocks are essentially conformable with the overlying shales and carbonates which floor the Great Valley; their structure, within the

limits expectable from differences in deformational competence and strati graphy, constitutes essentially a single structural unit with the Great Valle rocks. Their erosional resistance, however, causes the lowest Cambria rocks to combine topographically with the underlying crystallines to pro duce a pronounced highland which is recognized as a distinct physiographi province called the Blue Ridge from southern Pennsylvania to Georgia In eastern Pennsylvania, to the northeastern limit of the Great Valley, similar relationship exists between the valley rocks and a thinner clasti sequence. The oldest beds are apparently only middle Lower Cambria which, with a body of Precambrian crystalline rocks, forms the uplan called the Reading Prong of the New England physiographic province. Th succeeding Lower and Middle Cambrian is a somewhat variable sequenc of shale and carbonates usually found on the southeast side of the Grea Valley. This is followed by a great thickness of Upper Cambrian an Lower Ordovician carbonates showing considerable regional uniformity The lower Middle Ordovician is also largely characterized by limestones but they show depositional hiatuses and much more regional variability These limestones tend to become increasingly argillaceous upward in th section and are replaced by shales during the Middle Ordovician, thoug the gradational sequence is not everywhere complete. The shales are over lain by coarser sediments, in places of Upper Ordovician, and elsewhere o Lower Silurian age, which are erosionally more resistant and support th first linear ridge of the Valley and Ridge physiographic province. The Grea Valley is considered a subprovince of the Valley and Ridge—the first valle on the southeast side. It differs somewhat in scale and geologic feature from all other valleys of the province, however, to make a distinct sub province.

It may be reasonably supposed that during the Cambrian and Ordo vician, conditions in Dauphin and adjacent counties were approximatel comparable to those in the rest of the Great Valley area on the basis tha the exposed rocks were obviously deposited under similar conditions. Sub sequent geologic events, however, have produced complications in thi area. The northeastern end of the Blue Ridge, called South Mountain i southern Pennsylvania, disappears in south-central Cumberland Count plunging under the carbonates. In eastern Pennsylvania, the structure o the Lower Cambrian quartzites and Precambrian crystalline rocks in th Reading Hills is more complex than the relatively simple anticlinorium o South Mountain; but these rocks likewise disappear in the vicinity of Read ing in Berks County. As a result the usual simple pattern of the southeas side of the Great Valley, a ridge of conformably underlying clastic rock draped over a basement uplift, is absent from the vicinity of Reading acros Lebanon and Dauphin Counties into eastern Cumberland County. In it place a fault brings predominantly red shales, sandstones, and conglom

rates of the Triassic Newark Series in contact with various portions of ıe Cambro-Ordovician carbonate sequence.

The Newark Series is deposited in fault basins developed discontinuously om Newfoundland to South Carolina after all major folding and meta- ıorphism of this region had been completed. Through most of this belt ıe Triassic basins lie within a complex of highly deformed metamorphic ɔcks forming the Piedmont and New England provinces. In this setting, ıe Triassic sediments are more easily eroded than the adjacent crystalline ɔcks and form an area of relatively lower elevation that has been desig- ated the Triassic Lowland section. From southeastern New York to orthern Virginia the Triassic basins lie close to the northwestern margin f the crystalline rocks, on the northeast end separated from the Great 'alley only by the thin Reading Prong of the New England province, and n the southwest end only by the Blue Ridge. Approximately in the center f this span of close approach, between the Reading Hills and the nose f South Mountain, the Triassic basins actually encroach on the Great 'alley. In this situation the Triassic sediments are more erosionally re- istant than the adjacent carbonates, which gives rise to the accurate but aradoxical statement appearing in published reports on this area that The Great Valley is bounded on the southeast by the hills of the Triassic owland."

It is not to be inferred from this description that the older basement plifts were at one time continuous from the Blue Ridge to the Reading rong and were merely truncated in this area by later Triassic faulting. he Cambrian clastics and Great Valley carbonates of both the Reading ills and South Mountain wrap around the ends of each in such a manner s to demonstrate that these terminations are part of an older pattern of olding. The intervening area was one of relatively low basement during he pre-Triassic deformations. This basement configuration undoubtedly as a direct relationship to the structural peculiarities within the rocks of he Great Valley in this area.

In Pennsylvania the Great Valley has been divided into the Lehigh, Leb- non, and Cumberland Valleys separated by the Schuylkill and Susque- anna Rivers. This subdivision is historically old and cultural in origin, ut it is not without geologic significance. To a first order of approximation t might be said that geologically the three sections might be defined as hose lying adjacent to the Reading Prong, the Triassic Lowland, and the Blue Ridge respectively.

Internally each section is distinguished from the adjacent ones by dif- erences in tectonic style, that is, in the details and overall aspect of the eformation, and in stratigraphy. The latter difference is not extreme in he sense that the Great Valley, as a whole, maintains its physiographic nity by erosion of a grossly similar sequence of Cambro-Ordovician car-

bonates and shales; but, in greater detail, it is found that many formation which can be easily mapped through much or all of one section are suffi ciently different from rocks in an adjacent section that their precise equiva lents can be only approximately specified. As a result it has been neces sary to evolve a separate stratigraphic terminology for the rocks of eac section, representing real differences in the lithic sequence. For conveni ence in this report, the rocks belonging to the lithic sequence characteristi of a particular section of the Great Valley will simply be designated a the Lehigh Valley sequence, the Lebanon Valley sequence, or the Cum berland Valley sequence.

In this context a more precise geologic subdivision of the Great Valle may be made by distinguishing each section as that part underlain by it characteristic stratigraphic sequence. The divisions so drawn essentiall differ only in detail from those based simply on the gross geology and phy siography of the southeastern rim. Detailed mapping employing the mor recent stratigraphic refinements have not been completed in the easter part of the Lebanon Valley or the adjacent parts of the Lehigh Valley Hence, it is impossible to draw a precise line or zone of demarcation be tween these two sections by the stratigraphic criterion. Field reconnais sance and a survey of the available literature indicate that the change i less pronounced than between the Cumberland and Lebanon Valleys, bu that the southwest end of the Reading Hills or the Schuylkill River is a good approximation of the boundary.

The detailed study in Dauphin County discussed in the body of thi report, in conjunction with reconnaissance in eastern Cumberland County shows that, at least within the limestone portion of the section, the geologi boundary between the Cumberland and Lebanon Valleys as defined by th stratigraphic sequences is abruptly marked by a major overthrust havin marked stratigraphic differences between the upper and lower plates. Th position of this thrust within the shales of the Great Valley is less certainl known.

The Cumberland Valley sequence, though showing considerable devel opment of asymmetric to overturned folds and thrusting, in a regiona sense appears to be rightside up and at least parautochthonous. In th Lebanon Valley, on the other hand, the stratigraphic sequence is regionall inverted and the structure is dominated by numerous thrust faults. Man of these thrusts are intraformational and probably of small magnitude; bu several transgress more than a thousand feet of strata at such an angle a to indicate a minimum possible displacement of several miles. It seem probable that the cumulative displacement of all the thrusts, great an small, must be reckoned in tens of miles. These thrusts are characteristi of the entire length of the Lebanon Valley; but the intensity of the move ment, as reflected by destruction of primary structures within the roc

nits, by distributed shear, and by phyllitization of shaly partings, apparntly increases toward the west end of the valley. In western Dauphin and astern Cumberland Counties the entire inverted sequence including stratiraphically uppermost shales cuts across the carbonates of the Cumberland 'alley sequence, which apparently must continue into the Lebanon Valley n the subsurface. The stratigraphic and structural relationships make it vident that the Lebanon Valley sequence is part of the body of a major appe which must have moved a substantial number of miles near the Susuehanna River. The sole thrust of the Lebanon Valley sequence is here esignated the Yellow Breeches thrust from its several crossings of Yelow Breeches Creek in eastern Cumberland County. The southwesternmost proved extent of this thrust is its disappearance against the Triassic order fault at the nose of the plunging end of South Mountain. The ortheastern end is as yet less clearly defined, but the Lehigh Valley caronates appear to belong to a different structural system. The Lebanon 'alley nappe thus occupies the part of the Great Valley opposite the basement low between South Mountain and the Reading Hills. It seems very robable that the existence of this low was a significant factor in the appe emplacement.

STRATIGRAPHY

Carbonate exposure is notably poor in Dauphin County even by comarison with adjacent portions of the Great Valley. With the exception of xposures along Swatara Creek and to a lesser extent along other water ourses, natural outcrops sufficient to allow stratigraphic identification nd determination of structural attitude are rare. Most bedding determinaions indicated on the map in the broad interfluves are obtained from rtificial exposures. Actual tracing of lithologic contacts is largely deendent on mapping the differences in float fragments which are quite parse in many areas. In the eastern part of the county the mantling mateial is apparently entirely residual soil except for slope wash from the Martinsburg Formation and the Triassic at the margins of the valley. To he west, however, a veneer of alluvial silt and gravelly silt containing xotic pebbles apparently related to the higher gravel terraces which have een described in the Harrisburg-Highspire vicinity (Stose, 1928; Hickock nd Moyer, ms.) masks all other material over considerable areas.

The post-Chazyan limestones are generally distinctive and offer identiication problems only with respect to the gradation into Martinsburg hale. No single lithotype is diagnostic of any of the older formations. ome formations are characterized by particular lithologies, but the occurence of no major lithotype is entirely confined to a single formation. ome partial sections of stratigraphically well separated formations are so

similar that field discrimination must be based largely on stratigraph position. In view of these conditions it is obvious that single rock spe mens or small exposures are insufficient to differentiate formations.

The color descriptions used in this report are based on the *Rock Col Chart* (Goddard and others, 1951). With the exception of the weather surfaces on the magnesian rocks almost all of the carbonate rock colc fall in the neutral range dark gray (N3) to very light gray (N8). This sy tem is employed because it seems the only reasonably objective meth available. Workers experienced with the rocks of this area will witho hesitation, except for personal differences in marginal cases, recognize t distinction, for example, between "blue" gray and "dove-colored" lim stone though all may be subsumed under a single chart color. Very subt color distinctions are sometimes useful in stratigraphic discrimination b are hard to impart without reference to actual samples.

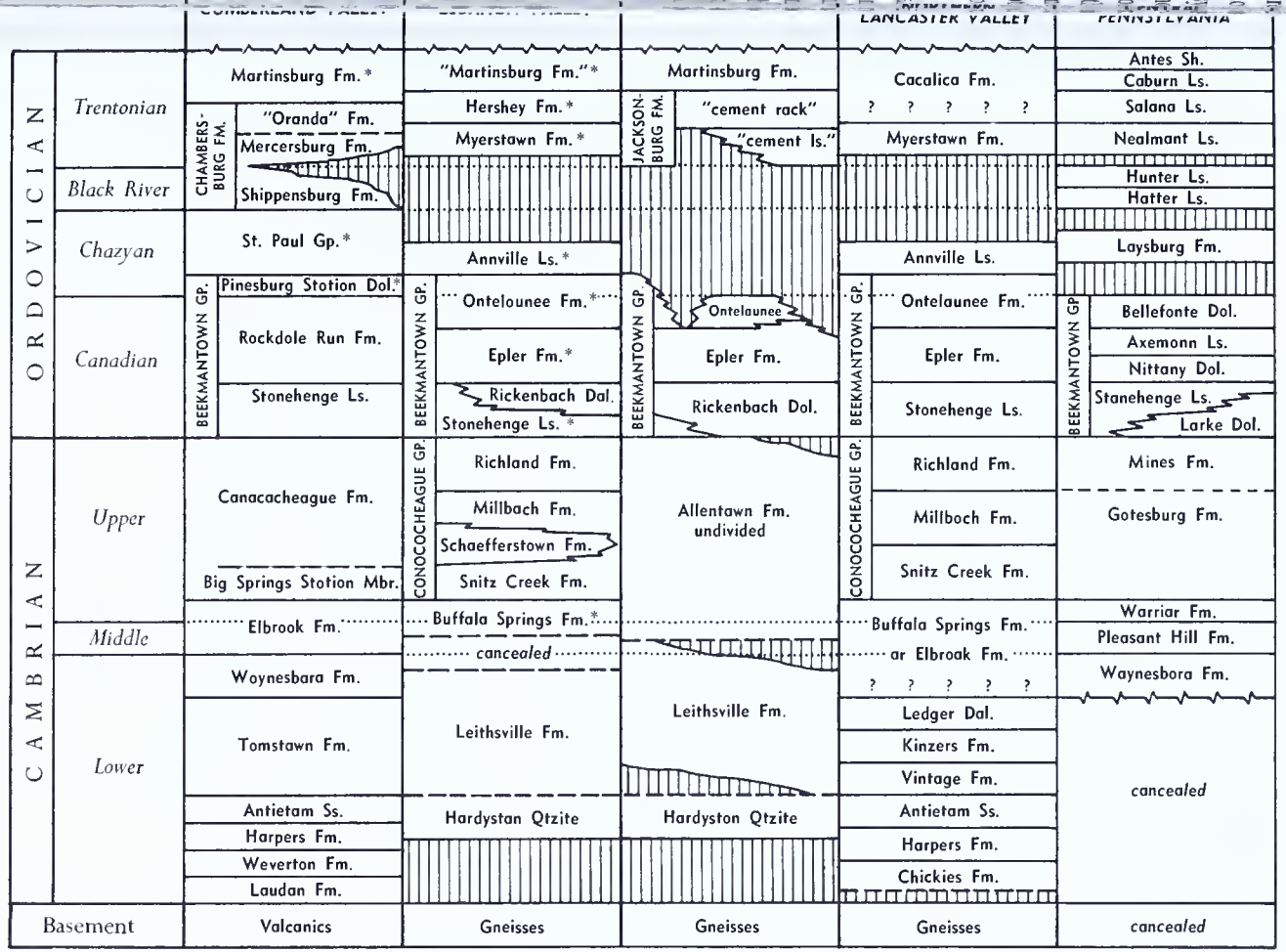
No new stratigraphic units are designated in this report, but certa questions concerning stratigraphic terminology have arisen in applyi existing names. The Stratigraphic Names Committee of the Pennsylvan Geologic Survey has reconsidered the status of names where doubtful ar determined to retain the existing names according to provisions of t *Code of Stratigraphic Nomenclature* (American Commission on Strat graphic Nomenclature, 1961), hereafter referred to as the Stratigraph Code, where applicable.

GENERAL CORRELATION

The carbonate rocks exposed in Dauphin County range from Midd (?) Cambrian to Middle Ordovician (Trentonian) in age. Age assignmen of the various formations are entirely on the basis of lithologic correlatic and stratigraphic position. Generally the rocks are sheared, recrystallize and complexly deformed so that fossil material which may have original been present has, for the most part, been destroyed or rendered unident fiable. The few occurrences of identifiable fossil material are consistent wi the age assignments but contribute nothing to refinement of the chronolog

Figure 2 shows the Cambrian to Middle Ordovician units typical of t full development of the Great Valley carbonate sequences and their a proximate correlation. The vertical scale is dictated by typographic co venience only and is intended to reflect neither duration of absolute tim nor stratigraphic thickness. The formations recognized in Dauphin Count are designated by asterisks. Except for the indicated cases of stratigraphi pinch-out the formations absent in Dauphin County are presumably struc turally concealed.

The basal contact of the emended Stonehenge Formation at Chamber burg in the Cumberland Valley (Sando, 1958), lies in an interval c about 300 feet lacking diagnostic fossils between Upper Cambrian an



* *Designates formations outcropping in Dauphin County.*

Figure 2. Correlation of Cambro-Ordovician formations of the Pennsylvania Great Valley and nearby areas.

Lower Ordovician faunal assemblages. The precise Cambro-Ordovici boundary is thus indeterminate to this extent, but for all practical purpos it is coincident with the lithic contact. Fragmentary fossil evidence indicat that the Stonehenge Formation of the Lebanon Valley is at least appro mately a temporal as well as lithic equivalent of that in the Cumberla Valley (Hobson, 1963). The combination of very poor exposure of t lower Stonehenge and the absence of diagnostic fossils in the underlyi rocks makes it impossible to assign a precise temporal Cambro-Ordovici boundary, but it is convenient and at least approximately correct to pla the boundary at the base of the Stonehenge Formation in the Leban Valley also. On the other hand the necessarily rather long-range lithic co relations to sections bearing well-established faunas suggest that epoch boundaries are generally not exactly coincident with formational co tacts. The age and correlation of these units shown on the table a suggested by several lines of reasoning but cannot be considered abs lutely established. The basis for correlation of individual formations w be discussed in the systematic description of each.

CAMBRIAN SYSTEM

The only Cambrian rocks exposed in Dauphin County are Middle (Cambrian of the Lebanon Valley sequence in the southeastern part of t map area. The thrust bringing these rocks over Lower Ordovician roc rises stratigrapically in western Lebanon County so that a full Upper Can brian sequence is present at the western edge of the Lebanon quadrang (Geyer and others, 1958). A complete Cambrian succession is present i the Cumberland Valley sequence in the Carlisle quadrangle (Stose, 195 about 10 miles west of Dauphin County. The Cambrian outcrop is tru cated at the extreme east edge of the quadrangle by the "Taconic thrus of Stose (1946, 1950) which is substantially identical with the Yello Breeches thrust of this report in position though not in structural inte pretation.

In both cases the rocks missing in Dauphin County are tectonically co cealed and are presumably represented in the deeper structure. A bri discussion of the Upper Cambrian rocks is given to facilitate compariso between the sequences.

Buffalo Springs Formation (Middle (?) Cambrian)

Name.—The Buffalo Springs Formation was defined by Gray and othe (1958) and Geyer and others (1958) as the lowest of five members of th Conococheague Formation as then mapped in Lebanon County followin the practice of Stose and Ljungstedt (1931). The Conococheague was i formally raised to group status and the members to formations by Gra Shepps, and others (1961). Continued work in these rocks has establishe

te probable equivalence of the Buffalo Springs to the Elbrook Formation (Middle Cambrian) of the Cumberland Valley, and the Conococheague roup of the Lebanon Valley has since been formally redefined (Geyer id others, 1963) to exclude it.

Distribution and Thickness.—To the present the term Buffalo Springs ormation has been applied only on the south side of the Lebanon Valley here it has been mapped from south of Womelsdorf, just west of the erks County line, westward across Lebanon County and three miles into stern Dauphin County. At both ends of this belt exposure is terminated post-depositional structures. Reconnaissance indicates that the Buffalo rings Formation continues eastward as a mappable unit at least into the per carbonate rock thrust plate south of Reading, but it is not presently nown if it can be distinguished in the Lehigh Valley sequence.

The exposed thickness of the formation is estimated by Geyer and hers (1963) as about 500 feet in the vicinity of Womelsdorf to 800 or 00 feet for a partial section near Lebanon about 10 miles to the west. his rapid thickening to the west suggests that there is little difficulty in lating this unit to the generally similar 3000 feet of the Elbrook Forma- n in the Carlisle quadrangle (Stose, 1953). Poor exposure and intense eformation leading to partial obliteration of the bedding makes any esti- ate of the exposed thickness in Dauphin County extremely tenuous. rude approximations suggest that somewhat less than the maximum thick- ess at Lebanon would suffice to provide the maximum crop width in auphin County, but only an indefinite fraction of the formation is ex- osed.

Character.—The formation consists of medium-to-heavy-bedded, finely ystalline limestones ranging from very light gray and sometimes pinkish ay to medium gray with the lighter colors predominant in most expo- ures, interbedded with subordinate light-gray to medium-gray, yellowish- ay-weathering dolomites and magnesian limestones. Shaly to silty lami- ae, not conspicuous in the fresh rock but weathering brownish are abun- ant. Disseminated silt is abundant in the purer looking interlaminae and me beds are sufficiently rich in terrigenous constituents to remain co- erent after leaching of the carbonate component. These beds are techni- ally calcareous shales in the sense that they are apparently composed of ss than half carbonates. The appearance of the fresh rock, however, is ot substantially different from the beds containing a smaller proportion f terrigenous clastics. In many of the exposures in Dauphin County and djacent parts of Lebanon County the conspicuous foliation in these rocks a fairly flat-lying cleavage marked by partings with a phyllitic sheen. his cleavage is generally approximately parallel to the bedding as shown y variations in gross lithology and rigorously parallel to the lamination

in much of the crop. The tectonic orientation of these laminae is ma apparent, however, in some crops where thin silty beds may be shov cutting across the cleavage in complex folds which become drawn o and broken apart into tectonic laminae. The oölites and cryptozoon be found in the type area of the formation to the east have not been reco nized in Dauphin County. It seems probable, however, that any eviden of their original presence would be destroyed under the condition of su stantial distributed translational deformations indicated by the structu in this area.

Limits.—The basc of the Buffalo Springs Formation is nowhere e posed in the area in which it has been mapped. In eastern Dauphin Coun and through most of Lebanon County it is faulted against the Triass Gettysburg Formation. In eastern Lebanon County the formation is unde lain by dolomites called Tomstown by Stose and Jonas (1935), but virt ally all of both formations as well as the actual contact are conceale under heavy colluvium (Geyer and others, 1963). The actual identific tion of the underlying formation as Tomstown Formation is in any eve problematical.

The top of the Buffalo Springs Formation is precisely defined in the ty area at Buffalo Springs, Richland quadrangle, Lebanon County as the (co formable) base of the first massive coarsely crystalline dolomite of t overlying Snitz Creek Formation. In western Lebanon County this conta is truncated by a thrust fault which emerges from the contact between t Richland and Stonehenge Formations and brings each of the successiv formations down to the Buffalo Springs Formation progressively over t Stonehenge Formation. Thus in eastern Dauphin County an indetermina upper portion of the Buffalo Springs Formation may be missing as a r sult of this thrust.

Exposure.—The Buffalo Springs Formation is poorly exposed in Dau phin County. The best representative exposures may be found in sever small abandoned quarries about 1.8 miles southwest of Campbelltow concealed in copses south of the township road. The southern conta against the Triassic rocks is nowhere exposed and presumably lies und a considerable thickness of slope debris in many places. The upper thru contact is likewise not exposed. Through much of its extent its positio can be only approximately defined by changes in the character of the flo with several hundred yards or more across strike intervening betwee outcrops. The position of the thrust is much more closely restricted, how ever, in the area of the window in the thrust plate about half a mile sout of U.S. 322, just east of the east branch of Spring Creek. At the time c examination, scattered exposures of the Buffalo Springs Formation an the overridden Ordovician with diverse attitudes could be found withi

relatively short distance. Construction of Hershey School facilities has bsequently been initiated in this area, and it cannot be anticipated what e character of exposure will be when this project is completed.

Correlation.—The correlation of the Buffalo Springs Formation will be scussed with that of the Elbrook Formation after a brief discussion of e Middle Cambrian of the Cumberland Valley sequence.

Elbrook Formation (Middle Cambrian)

Name.—The Elbrook Formation was defined by Stose (1906) at El- ook (Chambersburg 15′ quadrangle), Franklin County, Pa., in the Cum- rland Valley sequence. He subsequently extended the name to isolated posures southeast of the Triassic basin in Lancaster County (Stose and nas, 1922). The term has been applied by other workers southwestward the Great Valley to southern Virginia.

Distribution and Thickness.—The northeasternmost exposure of the El- ook Formation is near the eastern border of the Carlisle 15-minute quad- ngle (Stose, 1953) where the formation wraps around the end of the unging South Mountain fold and disappears under the Yellow Breeches rust and abuts against the Triassic border fault. Stose gives a thickness 3000 feet in the Carlisle quadrangle and likewise in the Chambersburg- lercersburg type area (1909). It seems reasonable to suppose this uni- rm thickness displayed for 40 miles along strike probably does not ange abruptly to the northeast. If this is correct, about 3000 feet of umberland-Valley-sequence Elbrook Formation is presumably present the deep subsurface of Dauphin County. Southwestward along the reat Valley from the type area the unit thins gradually to about 1500 et in southwestern Virginia (Butts, 1940), and equivalent strata beyond is point are differently subdivided.

Character.—The Elbrook Formation is an alternating sequence of im- ure limestone and dolomite generally quite similar to the Buffalo Springs ormation. Greenish calcareous shale beds in the Elbrook type area are ore conspicuous than the possibly equivalent argillaceous beds of the uffalo Springs, however.

Limits.—The base of the Elbrook Formation is readily apparent as the nderlying Waynesboro Formation is topped by slabby sandstone and urple siliceous shale. The basal member of the overlying Conococheague ormation is dolomitic and sandy, producing a difference in float and soil haracter that is readily apparent even in areas of poor exposure. In both ases the contacts are apparently gradational, but the gradation does not xtend through a large stratigraphic thickness.

Age and Correlation.—Stose (1906) assigned the Elbrook Formation a Middle Cambrian age on the basis of a sparse restricted faunule and conformable to gradational contacts with adjacent formations of established Lower and Upper Cambrian age. Subsequent work (Resser, 1938; Wilson, 1952) places the base of the formation quite low in the Middle Cambrian but as much as 700 feet of the upper Elbrook has a Dresbachian (lower Upper Cambrian) fauna lacking only a few elements found in the basal Conococheague Big Springs Station Member. Wilson (1952) demonstrates the correlation of the Big Springs Station Member with the lower sandy member of the Gatesburg Formation in central Pennsylvania. As the underlying Waynesboro Formation is recognized in both areas, the Elbrook Formation is essentially equivalent to the Pleasant Hill and Warrior Formations of central Pennsylvania. There seems to be little doubt about the general position of the latter formations in the standard Cambrian faunal sequence indicating a Middle Cambrian and lower Dresbachian age for the Elbrook Formation.

The Buffalo Springs Formation is considered Middle (?) Cambrian on the basis of its lithologic similarity to the Elbrook Formation and the comparable relation of both to the correlative basal Conococheague Group beds. Like the Elbrook Formation it may include Dresbachian at the top. As noted in the descriptions, the Buffalo Springs Formation differs from the Elbrook in the absence of definite shale beds, whereas the Elbrook Formation contains a proportion of greenish calcareous shales. The laminated limestones dominating both formations are very similar, however. The very light-gray to pinkish-gray marblelike beds containing disseminated quartz silt are quite characteristic of these formations in both sequences though the same lithology also occurs higher in the section in both. The Elbrook Formation of the Cumberland Valley has not been studied in sufficient detail to demonstrate with any certainty that the shaly beds diminish northwards to converge in character with the Buffalo Springs Formation, but the change across the tectonic boundary between the sequences is no greater than is found in units considered equivalent higher in the section.

The dolomites older than the Buffalo Springs Formation in the eastern part of the Lebanon Valley were called Tomstown (type area beneath the Waynesboro in the Cumberland Valley) by Stose (Stose and Ljungstedt, 1931; Stose and Jonas, 1935). While the rocks of this area have approximately the same lithology and could include the same interval as the Tomstown Formation of the Cumberland Valley they are at least equally comparable and geographically closer to the Leithsville Formation (Wherry, 1909; Howell and others, 1950) of the Lehigh Valley. As made clear by Miller (1941), Stose and Jonas correlated these rocks with the Tomstown Formation on the basis of a far-travelled-overthrust hypothesis for

he structure of the Reading Hills. Buckwalter (1962) summarizes the onsiderable controversy developed over this hypothesis and shows on the asis of recent aeromagnetic surveys and detailed mapping that the hy- othesis is untenable. Recent workers in the Lehigh-Valley Leithsville Howell, Roberts, and Willard, 1950; Willard, 1955) assign a tentative Middle Cambrian age to the formation; but, on the basis of the descrip- ons they give, with at least locally gradational contacts to both the ower Cambrian quartzites and the overlying Allentown Formation, it ight very well include equivalents of the Cumberland Valley sequence omstown, Waynesboro, and part of Elbrook Formations.

Gray, Shepps, and others (1960) designated the Lebanon Valley oc- urrences as Leithsville Formation, but Geyer and others (1963) reverted Tomstown Formation in mapping the Womelsdorf quadrangle. Geyer ersonal communication), however, indicates this choice was based on n assumed equivalence of the two terms, which is by no means demon- trated. The Lebanon Valley occurrences are almost 50 miles removed rom the closest exposures directly traceable to the Tomstown type area; ess than 10 miles divide them from rocks traceable to the Leithsville type ection with the Hardyston Formation subjacent in both areas. Conse- uently, the term Leithsville Formation seems much more appropriate in he Lebanon Valley. This seems particularly desirable in view of the fact hat the exact age of the Lebanon Valley exposures is at least as doubtful s the type Leithsville Formation, whereas the Tomstown Formation and s definite equivalents southwestward in the Great Valley have a fauna ith a definite position in the standard Cambrian faunal sequence. It is ot even certainly known that any part of the Leithsville Formation is of omstown age or that any sort of depositional continuity existed between he two formations.

If the strata below the Buffalo Springs Formation are considered Leiths- ille the relation between the lower contacts of the Elbrook and Buffalo prings Formations is uncertain. On the basis of the published descriptions Wherry, 1909; Miller, 1941, Howell, Roberts, and Willard, 1950; Wil- ard, 1955), it seems probable that Buffalo Springs Formation equiva- nts are included in the lower portion of the undivided Allentown For- ation in the Lehigh Valley. The more recent reports suggest that the llentown-Leithsville contact, where gradational, should be younger than he Elbrook-Waynesboro contact; but the lithic description of both is omparable.

Conococheague Group (Upper Cambrian)

Name.—Stose (1908) designated the Upper Cambrian rocks of the Cum- erland Valley as the Conococheague Formation from exposures along Conococheague Creek in Franklin County. He subsequently extended the

term to all supposed Upper Cambrian rocks in the Pennsylvania Great Va ley (Stose and Ljungstedt, 1931) and Piedmont (Stose and Jonas, 1922 Other workers have extended the term to southwestern Virginia (cf. Butt 1940). As indicated in discussion of the Buffalo Springs Formation, th Conococheague has been formally raised to group status in the Lebanc Valley (Geyer and others, 1963) excluding the Buffalo Springs Form tion which was previously mapped as part of the Conococheague Form tion.

Distribution and Thickness.—The Conococheague Group is not repr sented by exposure of either sequence in Dauphin County but it is pr sumably present in the subsurface in both. Apparently complete Upp Cambrian sections are exposed in both Lebanon and Cumberland Counti to the east and west. The nearest areas mapped in detail, the Lebanc quadrangle (Geyer and others, 1958) and the Carlisle quadrangle (Stos 1953) both indicate a thickness of about 2000 feet, though the latter in cludes probably about 200 feet now considered the Stoufferstown Memb of the Stonehenge Formation (Sando, 1958). From the vicinity of Lebanc toward the east, the Conococheague Group thickness is about 3200 feet Womelsdorf (Geyer and others, 1963). This relationship suggests the prol ability of westward thinning toward Dauphin County, but field work b Geyer and others in the Palmyra quadrangle indicates that any such thi ning is less abrupt than from Womelsdorf to Lebanon. Wilson (1952) i dicates that, allowing for the subsequent removal of the Stoufferstow Member, the Conococheague Formation has a fairly uniform thickness about 1800 feet throughout the Cumberland Valley. In the absence of co trary evidence it seems reasonable to suppose that about 1800 feet Conococheague may be present in both sequences in the deeper structure Dauphin County.

Subdivision and Character.—The Conococheague Group of the Lebano Valley is now recognized as comprising four formations: the Snitz Cree Formation, predominantly a dolomite containing some sandy beds; th Schaefferstown Formation composed of fairly dark terrigenous clastic lam inated limestone; the Millbach Formation, a pure-looking light-colore limestone containing considerable disseminated silt and locally sandy laye near the top; and the Richland Formation which is predominantly dol mite.

Wilson (1952) studied the Conococheague Formation of the souther Cumberland Valley and separated a basal sandy dolomite, the Big Spring Station Member, overlying the Elbrook Formation. This member may b laterally persistent and a correlative of the Snitz Creek Formation. Th remainder of the formation has not been subdivided in the Cumberlan Valley, but the top in the Chambersburg type area (Stose, 1909) was re

efined by Sando (1958) by separating the limy Stoufferstown Member om the underlying dolomite-bearing rocks and including it in the over- ing basal Ordovician Stonehenge Formation on paleontologic criteria. he effect of this revision is to make the Cambro-Ordovician contact lithi- ally as well as faunally more similar to that recognized by Hobson (1957, 963) at the base of the Ordovician rocks of the Lebanon Valley sequence.

Sandy beds in the upper part of the Cumberland-Valley Conococheague ormation have been shown (Wilson, 1952) to thicken northwestward with convergent trend toward the upper Gatesburg Formation of central ennsylvania, showing a northwestern source for this detritus. Comparable andy units are present but less well developed in the Lebanon Valley ichland Formation, and at the top of the Millbach Formation. The di- inished quantity of sand in the Lebanon Valley sequence is consistent ith a more southeasterly site of deposition for the allochthonous rocks.

The Conococheague Formation of the Shenandoah and Cumberland alleys shows an increasingly dolomitic gradient northeastward, ranging om about 15 percent dolomitic in Washington County, Virginia to about 5 percent dolomitic near Carlisle. A similar gradient exists east of the usquehanna River where about 50 percent dolomite occurs in the type rea of the Lebanon-Valley Conococheague Group subdivisions, and only ubordinate limestone is recognized in equivalent strata in the Delaware iver area and New Jersey. The difference in dolomite content between ie exposures in the Carlisle quadrangle and those in western Lebanon ounty, however, is much greater than would be inferred for the inter- ening distance on the basis of the gradient extrapolated from the con- guous belts. This facies discontinuity seems best explained by substan- al movement on the thrust known to affect the Lebanon Valley sequence.

Limits.—All published reports indicate gradational contacts of the Con- cocheague Group to the underlying Elbrook and Buffalo Springs For- ations in the Cumberland and Lebanon Valleys respectively. Similarly radational contacts are indicated with the overlying Stonehenge Forma- on in this region. An unconformity is present at the top of strata equiva- nt to the Conococheague Group at the Delaware River but is absent to ie southwest at the Lehigh River.

Age and Correlation.—As mentioned in the general discussion of cor- elation, the upper contact of the Conococheague Group is believed sub- antially coincident with the Cambro-Ordovician boundary. The Big prings Station Member at the base of the Cumberland Valley Conoco- heague has a *Crepicephalus* Zone faunal assemblage and is laterally gra- ational westward into the lower sandy member of the Gatesburg Forma- on of central Pennsylvania (Wilson, 1952). These relations indicate that ie basal contact is close to the beginning of the Upper Cambrian, but

the Upper Cambrian fauna extends down into the upper part of the unde lying Elbrook Formation. As both the Gatesburg and the Conococheagu Formations are succeeded by reasonably well correlated occurrences of th Stonehenge Formation the precise equivalence of the two seems adequatel demonstrated. Only a sparse fauna is known from the Conococheagu Group of the Lebanon Valley, and it has not been adequately describe to permit a precise faunal correlation. It seems reasonable to suppos however, that it is essentially synchronous with that in the Cumberlan Valley.

While it seems probable that future mapping may demonstrate the po sibility of recognizing equivalents of the Lebanon-Valley Buffalo Spring and Conococheague units in the Lehigh Valley, the use of Conococheagu Formation for the undivided Allentown Formation (Wherry, 1909) in th manner of Stose and Ljungstedt (1931) seems most undesirable. The A lentown Formation (restricted) of Howell and others (1950) of the Dela ware River area seems to be the approximate temporal equivalent of th Conococheague; but the recognition of the restricted formation in th Lehigh Valley is dependent on faunal criteria and is not apparently mappable unit. Hence, the local name Allentown Formation in the old usage seems presently most suitable in the Lehigh Valley.

ORDOVICIAN SYSTEM

Almost the entire section of the Ordovician carbonates of the Lebanc Valley sequence is represented in eastern Dauphin County. Farther we in the county structural complications conceal various units. The thru under the Lebanon Valley sequence conceals much of the Ordovician a well as all of the Cambrian of the Cumberland Valley sequence. As th northern border of the Cumberland Valley carbonates in Dauphin Coun is also tectonically complex, only a fragmentary section is present.

Beekmantown Group (Lower Ordovician)

Name.—The name Beekmantown has been widely used in the Appa lachian area to designate Lower Ordovician carbonate rocks, althoug this designation includes rocks not represented at the type section in Ne York (Clarke & Schuchert, 1899) as restricted by Ulrich and Cushir (1910). Stose (1908) applied the name to the rocks between the Conoc cheague Formation and the "Stones River" (now St. Paul Group) in th Cumberland Valley. Ulrich (1911) was apparently the first to apply th name to rocks east of the Susquehanna River. The Shoreham, Vermon section of Brainerd and Seely (1890), where an unconformity occurs b neath the overlying lower Chazyan, is generally regarded as the referenc section for this broader use of the name Beekmantown.

Distribution and Thickness.—With the possible exception of some windows through the Triassic sediments, the southwesternmost occurrence of the Lebanon Valley sequence Beekmantown Group is at Bowmansdale, Cumberland County, about 8 miles west of the Susquehanna River. From this point northeasterly across Dauphin County, most of the exposed carbonates of the Lebanon Valley sequence are of the Beekmantown Group. Owing to structural complications, however, the full thickness of the group is not represented in the outcrop belt southwest of the Annville vicinity in Western Lebanon County. The exposed thickness in Dauphin County ranges from less than 1000 feet on the west to probably about 3000 feet in the east, but the total thickness including the concealed portion is apparently about 3500 feet. This represents the thickest section of the Lebanon Valley-Beekmantown Group which thins northeasterly to about 2300 feet in Berks County (Hobson, 1957, 1963), 2000 feet at Northampton, and 1600 feet at the Delaware River (Hobson, 1963).

A small thickness of Cumberland Valley sequence Beekmantown Group rock is exposed on the north side of the northern limestone belt in Dauphin County from south Harrisburg to Rutherford. This is the northeasternmost exposure of these rocks, and it is structurally isolated from the main belt of Beekmantown Group outcrop in the Cumberland Valley. The main outcrop belt extends as far northeast as Shiremanstown, about 7 miles west of the Susquehanna River, and is terminated by the Yellow Breeches thrust. Recent work in southern Pennsylvania by Sando (1957, 1958) and Pennsylvania Survey geologists indicates the presence of more than 3500 feet of the Beekmantown Group, which is considerably greater than the 2300 feet indicated by the early work of Stose. Stose (1953) reports only 2600 feet of Beekmantown in the Carlisle quadrangle; but, in the absence of well-exposed complete sections, this necessarily represents an extrapolation from his southern Pennsylvania sections. The Beekmantown Group may thin somewhat northeastward from southern Pennsylvania but certainly exceeds the thickness given by Stose in the northeastern end of the Cumberland Valley. Southwest of southern Pennsylvania and Maryland the group thins to 3000 feet in northern Virginia and 1200 feet in southwestern Virginia.

Subdivision.—The Beekmantown of the southern Cumberland Valley was studied by Sando (1956, 1957) who raised it to group status and defined the three formations, Stonehenge, Rockdale Run, and Pinesburg Station. The subdivision was extended north to the Chambersburg area and the base redefined by Sando (1958). Reconnaissance and field mapping currently in progress by the Pennsylvania Geologic Survey indicate that the subdivision is valid for the entire Cumberland Valley.

The Beekmantown of Berks County was defined as a Group by Hobson (1957) who established four formations, Stonehenge, Rickenbach,

Epler, and Ontelaunee, which have been mapped through much of th Lebanon Valley (Geyer and others, 1958 and 1963; Gray and other 1958). The regional distribution and correlation of these formations treated by Hobson (1963). It is readily apparent from Hobson's region correlation charts and descriptions, though he does not expressly state i that the lower two of his (1957) Beekmantown-Group formations are la erally gradational equivalents of each other. They are described as strat graphically successive formations at the type area and are conveniently s mapped in most of Lebanon and western Berks Counties. In Dauphi County, however, the entire interval is represented by the "lower" Ston henge Formation, while only the "higher" Rickenbach Formation is pre ent east of the Schuylkill River.

Individual formations of the Beekmantown Group subdivisions will b treated in more detail in subsequent individual descriptions.

Limits.—All descriptions indicate gradational contacts between th Beekmantown Group and the underlying Conococheague Group througl out the Cumberland and Lebanon Valleys. A minor unconformity is pre ent in the eastern Lehigh Valley at the Delaware River but disappears ea of the point where the Lehigh River crosses the Beekmantown outcrop.

In southern Pennsylvania and adjacent areas the top of the Cumberlan Valley Beekmantown Group is "vague" (Neuman, 1951). It is defined a being between the dolomites of the uppermost Beekmantown Group an the overlying limestones of the St. Paul Group. This level varies about 10 feet stratigraphically depending on local conditions influencing dolomitiz tion. The impression is that the established unconformity to the southwe in Virginia is absent here and deposition was continuous. Northwestwar in the Cumberland Valley the strata have not been studied in sufficient de tail to establish the relationships. The upper dolomites of the Beekmar town Group are apparently, at least, sporadically present throughout th Cumberland Valley, indicating that no substantial thickness of Beekmar town was eroded, and any interval of nondeposition was rather brief.

Through most of the Lebanon Valley, the Beekmantown Group is sai to be disconformably overlain (Gray, 1952; Prouty, 1959) by the hig calcium Annville Limestone. The contact is abrupt and usually sheare where exposed, but all bedding discordances are structural; stratigraphi arguments leading to the inference of a substantial hiatus are subject t other interpretation. East of Womelsdorf the Annville Limestone is cu off and does not appear in Berks County or the Lehigh Valley. Wher the Annville Limestone is absent, Trentonian limestones and shales re on an unconformable surface apparently having considerable erosiona relief.

Age and Correlation.—Beekmantown is commonly understood to ind cate carbonates of Lower Ordovician (Canadian) age. The base of th

eekmantown Group in the Cumberland and Lebanon Valleys, defined as e lithologic change from the underlying Conococheague Group, for all ractical purposes coincides with the Cambro-Ordovician faunal boundary. he uppermost part of the Beekmantown Group in the Pennsylvania Great alley, however, may in part be younger than Canadian. In the southern umberland Valley, uppermost Beekmantown is apparently gradational to middle Chazyan strata (Sando, 1957; Neuman, 1951). Recent work eastern Pennsylvania indicates the post-Beekmantown unconformity ay be above some Chazyan beds (Willard, 1958; Hobson, 1963). It is pparent, therefore, that the well-entrenched usage of Beekmantown in ie Great Valley of Pennsylvania differs slightly from that which is com- ionly understood elsewhere.

The Beekmantown Group of the Lebanon Valley sequence shows a outhwestward gradient of increasing thickness and decreasing dolomite ontent. The Cumberland Valley sequence Beekmantown is consistent with is gradient in being still thicker and less dolomitic, but there is a dis- ontinuity at the tectonic juncture between the sequences. As only the ppermost part of the Cumberland Valley Beekmantown is exposed in auphin County, only such detailed descriptions of the lower part are ven as are required to develop the correlation of the Lebanon Valley quence.

Stonehenge Formation

Name.—Stose (1908) applied the name Stonehenge Limestone to the west member of the Beekmantown Formation from the section at the llage of Stonehenge (now part of Chambersburg) in the Cumberland alley. Lithically and faunally similar strata in the interior anticlines of e Valley and Ridge were given formational status with the same name y Ulrich (1911). It was raised to formational status in the southern Cum- erland Valley by Sando (1956, 1957). He also revised it in the Cham- ersburg type area (1958) by including the uppermost 200 feet of the onococheague Formation, as mapped by Stose (1909), in the Stone- enge as the Stoufferstown Member on the basis of a lower Ordovician ilobite assemblage and closer genetic affinity to the overlying rocks. omparable rocks in about the same stratigraphic position in western erks County were assigned to the Stonehenge Formation by Hobson 1957, 1963) and have been mapped through much of the Lebanon Valley y the Pennsylvania Geologic Survey.

Distribution and Thickness.—In Dauphin County, the Stonehenge For- ation outcrops only on the eastern edge where a partial section is ex- osed of a sequence which is about 1500 feet thick where fully exposed few miles to the east near Annville (Geyer and others, 1963). At its estern end this belt of Stonehenge Formation outcrop abuts against the

Triassic border, and the lower contact is concealed under the Buffa Springs Formation of a thrust sheet.

In the Cumberland Valley the Stonehenge Formation last appears t the eastern border of the Carlisle 15-minute quadrangle about 8 miles fr the Susquehanna River, where it starts to wrap around the nose of t South Mountain fold and disappears under the Yellow Breeches thru In the type area near Chambersburg, as redescribed by Sando (1958), t redefined formation is about 1000 feet thick including 217 feet of t newly added Stoufferstown Member. The upper member, correspondi to Stose's original description of the formation, Sando reports to be abo 800 feet thick. This is considerably greater than the 485 feet reported Stose (1909). In the Carlisle quadrangle Stose (1953) reports about 6 feet of the Stonehenge Limestone. No sections are adequately exposed f a precise measurement. In view of the low thickness Stose reports Chambersburg, it seems probable that the thickness he gives at Carlis which is based on a similar structural interpretation, is also too small. we assume that his measurements were consistent in the two areas, t upper member of the Stonehenge Formation thickens somewhat nor easterly from the type section, but this is not well established. The Sto ferstown Member is apparently present in the Carlisle area, but its thi ness has not been determined. In the southern Cumberland Valley fr Chambersburg south through Maryland the Stonehenge Formati (emended) is persistently about 1000 feet thick (Sando 1957, 1958) in cating no regional gradient. In the absence of reliable measurements the northeastern part of the valley the same 1000-foot thickness is p haps the best approximation presently available for the Carlisle area.

In the eastern part of the Lebanon Valley Hobson (1963) gives a r erence section for the Stonehenge Formation at Glenside in Berks Coun A total thickness of 250 feet is measured and three members are rec nized nearby at Wyomissing. Traced northward along the local strike fr Wyomissing, the unit has entirely disappeared in less than 10 miles a is not recognized in the Lehigh Valley. Southwestward from Berks Cou the formation thickens to the maximum reported thickness of 1500 f near Annville in the western part of the county. Southwest of the An ville area the base is structurally concealed to the end of the outcrop b in Dauphin County.

The Stonehenge Formation is the only formation of the Great Val carbonates which maintains clear lithic identity between the Cumberla and Lebanon Valley sequences, and also the only one which has been e tended to central Pennsylvania. It is also recognized in the Piedmont f northern Lancaster County. Unusually extensive lateral homogeneity f depositional environment is implied during the interval of Stonehenge d position.

Character and Limits (Cumberland Valley).—In the Chambersburg type
ea Sando places the lower contact of the Stonehenge Formation where
first thin-bedded limestone containing numerous penecontemporaneous
nglomerate beds and only small seams and splotches of dolomitic ma-
ial gradationally succeed interbedded laminated limestones and dolo-
tes of the uppermost Conococheague Formation. Mechanical limestones
minate the body of the formation. The lower Stoufferstown Member is
nost entirely composed of autoclastic edgewise conglomerates which are
en oölitic; beds composed of clay-to sand-size fragments are abundant
the upper part of the formation. Massive fine-grained algal limestone
ds are abundant in the Maryland type area but much less common at
ambersburg, and are not certainly recognized in the northeastern part of
valley. Chert of any kind is rare in this section and apparently through-
t the Stonehenge of the Cumberland Valley. The upper contact is placed
the base of the first dolomitic limestone of the Rockdale Run Forma-
n, about 30 feet below a chert zone composed of silicified cryptozoons.
e float from the cryptozoon chert is used as the mappable base of the
ockdale Run Formation through much of the Cumberland Valley.

ure 3. Stonehenge Formation in southeastern Dauphin County. Conspicuous horizontal
oliation is cleavage, compass is aligned on obscure bedding.

Character and Limits (Lebanon Valley).—The base of the Stonehenge
rmation is not exposed at or near the reference section in Berks County
ere a persistent thick covered interval occurs between Cambrian and

Ordovician exposures; but it is precisely identified by Gray and oth (1958) at the type section for the uppermost Cambrian Richland Form tion where a sharp change from the primarily dolomitic beds of the Ric land Formation to fragmental limestones of the Stonehenge Formation exposed.

The Stonehenge Formation is too poorly exposed in Dauphin Cou to permit precise characterization. The fragmentary exposures suggest th the sequence is similar to that at Womelsdorf where Geyer and oth (1963) recognize two members. The lower member is primarily thin- heavy-bedded, medium-dark-gray, finely crystalline limestone with th dark-weathering shale laminae. Coarse mechanical edgewise conglomera and thin beds and lenses of calcarenite are common. Some thin beds fossil fragmental limestone are also found. Thin beds of medium-gray, y low-gray weathering, finely-crystalline dolomite are irregularly interbedd with the limestones and may locally compose up to 20 percent of t member. Nodular chert is reported as common but is first noted in Hc son's (1963) Lebanon County sections at 261 feet above the Richla Formation, about at the same level as the basal Rickenbach Formati chert in central Berks County. The chert apparently becomes less abunda to the southwest in Dauphin County; however, more chert is evident the Stonehenge than other formations of Dauphin County.

The upper member is characterized by medium-gray, heavy-bedded massive, finely crystalline limestone with abundant dark-weathering, th shaly to silty laminae. Thin beds and lenses of calcarenite are comm Dolomite is rare in the upper member; the top of the formation is plac at the base of the first dolomite bed in a gradational sequence to t typical dolomites of the Rickenbach Formation where it is present.

The upper contact of the Stonehenge is vertically gradational into t overlying Rickenbach dolomite through a fairly thin zone in most of t Lebanon Valley. However, not far southwest of Annville, about 4 mi east of the Dauphin County line, the Rickenbach Formation pinches and the Stonehenge Formation passes up-section, apparently gradational to the Epler Formation. In the absence of the Rickenbach Formation t contact for mapping purposes has been placed above the highest occ rence of limestone with dark-brownish-gray to black shale laminae, or l low the lowest heavy dolomite interbeds of the Epler Formation.

The limestones with thin dark shaly laminae may well be some form algal mat deposit, but definite algal structures are not recognized in t Lebanon Valley except in the uppermost part of the Berks County r erence section. The original depositional character of the finer grained b is hard to specify, as metamorphism has produced a very finely crystall mosaic in the carbonates and made the shaly partings phyllitic. Defin algal structures such as cryptozoons, which are present in the Cumberla

alley Stonehenge Formation, have survived the metamorphism in the ambrian formations of the Lebanon Valley sequence. The absence of ch structures must, therefore, be a depositional rather than metamorphic enomenon.

There are indications that algal structures decrease in abundance northsterly in the Cumberland Valley so their absence in the Lebanon Valley no positive evidence of a discontinuity along strike. The metamorphism the Lebanon Valley, however, increases southwesterly toward the Cumrland Valley, but does not affect it. The dolomite and chert are disctive elements that do not appear in the Cumberland Valley sequence.

Exposure.—The best readily accessible exposures of the Stonehenge Formation in Dauphin County are found along and to the west of the secdary road running south from U.S. 322 just east of the Hershey School ospital at the border of the Hummelstown and Palmyra quadrangles. At me of these crops careful examination is required to determine bedng characteristics, since the conspicuous foliation is a nearly horizontal eavage, which in places has produced a tectonic compositional bandg. Shale laminae, whether depositional or tectonic, are much more phyllic than to the east in Lebanon County. No fossils but pelmatozoan plate e known from these rocks.

Age and Correlation.—On the basis of a substantial described fauna ndo (1957, 1958) correlates the type Stonehenge Formation with the asconade Dolomite of the North American standard section. The exact sition of the Cambro-Ordovician faunal boundary is uncertain within an terval of 362 feet which embraces the lithic contact but lacks diagnostic ssils.

At his Berks County reference section, Hobson (1963) recognizes three embers. The middle member, extending to within 60 feet of the top of is thin section, appears lithically identical to the Stoufferstown Member the base of the Cumberland-Valley-sequence Stonehenge. Hobson's thin per member contains a few fossil forms questionably correlated with rms in the thick upper member at Chambersburg. In view of the lateral adation between the Stonehenge Limestone facies and the Rickenbach olomite facies, and the much greater thickness of the Stonehenge Formation where the Rickenbach is absent, it seems apparent that only the wer part of the type Stonehenge interval is present in the Berks County ction. At the maximum Lebanon Valley section near Annville the Stonenge Formation is thicker than in the type area and makes up a larger oportion of the total thickness of the Beekmantown Group. If depositnal rates were approximately uniform, this would imply that the uprmost Stonehenge Formation at Annville might be younger than the mparable rocks of the Cumberland Valley. Diagnostic fossils to eval-

uate this possibility have not been found. In the absence of contrary ev dence the simplest and most reasonable hypothesis seems to be that th lithically similar strata having thickness of the same general order we deposited at about the same time.

Rickenbach Formation

The Rickenbach Formation pinches out stratigraphically just east Dauphin County, but it merits brief discussion in this report for its bea ing on the Stonehenge-Epler contact and regional correlations. Hobs (1957, 1963) named the formation for about 560 feet of dolomite lyi between the Stonehenge and Epler Formations with apparently gradation contacts near Rickenbach in Berks County. Though Geyer and othe (1963) report a probable thickness of 800 feet at Womelsdorf, the form tion shows an over-all thinning trend southwesterly and pinches out noted. Through the same interval the underlying Stonehenge Formati thickens about 1000 feet. To the northeast of the Rickenbach type ar the Stonehenge Formation rapidly disappears; and A. A. Drake (cf. Ma Kenzie, *in* Ryan, 1961) recognizes the Rickenbach Formation as the olde Ordovician unit in the Lehigh Valley, apparently lying conformably on t Cambrian. Hobson (1963) makes similar observations in his regional di cussion. The Epler Formation also thickens from northeast to southwe above the Stonehenge-Rickenbach overlap but only about proportionate the thickening of the entire Beekmantown Group. Thus, while it is po sible that some of the southwestward thinning of the Rickenbach is a tributable to lateral gradation into Epler lithology, it seems highly pro able that most if not all of the change is due to complete lateral gradati betwecn the Stonehenge and Rickenbach Formations with the dolomi facies expanding through Stonehenge-Rickenbach time. By this interpr tation the situation in the Lebanon and Lehigh Valleys is closely analogo to the relation bctween the Stonehenge and Larke Formations in centr Pennsylvania. In this case the similarity between the Lebanon Valley s quence and the central Pennsylvania Beekmantown is less than might inferred from gross stratigraphy. As shown on the legend of the Geolo Map of Pennsylvania (Gray, Shepps, and others, 1961) in both areas the are four Lower Ordovician formations alternately characterized by pr dominance of limestone or dolomite. If Stonchenge-Larke is equivale to Stonehenge-Rickenbach, however, the Nittany Dolomite of central Pen sylvania must be equivalent to the lower part of the Epler Formation.

Epler Formation

Name.—Hobson (1957) gave the name Epler Formation to int bcdded limestones and dolomite lying with transitional contacts to t

dominantly dolomitic Rickenbach and Ontelaunee Formations below and above, as exposed east of Epler School along the Schuylkill River in Berks County.

Distribution and Thickness.—In Dauphin County the Epler Formation occupies a major part of the Lebanon-Valley-sequence outcrop belt. The full thickness of the formation outcrops from the eastern county line to a point about 1.7 miles east of Hummelstown where the Triassic border cuts off the lower contact. Exposure does not permit accurate measurement of a complete section in this area, but structural relations indicate a thickness of about 1300 feet. West of Swatara Creek in the Steelton belt the Epler Formation overrides the younger Ontelaunee Formation and is the only Lebanon-Valley-sequence Beekmantown unit recognized in the Steelton belt to its southwestern limit at Bowmansdale in Cumberland County.

Northeastward from Dauphin County the Epler Formation thins gradually to about 1000 feet in the vicinity of Lebanon (Geyer and others, 1963) and 800 feet in the Berks County type area. The beds show variations in stratigraphic detail along strike, but the interbedded unit forms a distinct entity from the southwesternmost exposures of the Lebanon Valley sequence in eastern Cumberland County through the Lebanon and Lehigh Valleys and into New Jersey. It may also be recognized directly overlying Stonehenge lithology in the northern Lancaster County Piedmont.

Character.—In Dauphin County the Epler Formation is characterized by heavy- to very heavy-bedded (typically 1 to 4 feet), distinctly to strongly laminated, finely crystalline limestone with subordinate interbeds of medium-to heavy-bedded (typically 6 inches to 2 feet), massive to faintly laminated, medium-dark-gray, grayish-yellow-weathering, finely crystalline dolomite and magnesian limestone. The dolomite is apparently fairly uniform in character throughout the section, but varies in abundance both stratigraphically and along strike. It was substantially more brittle during deformation than the adjacent limestones, with the result that it is much more highly fractured than the adjacent beds and in places is broken into rubdins. The intense jointing of the dolomites has had several effects: the weathered surface shows an "elephant hide" texture; a boxwork of milky secondary quartz sometimes forms in the joints, locally to the extent of almost complete replacement of the bed; and solution activity has to large extent been concentrated along the fractured beds so that solution cavities are much more common in the normally less soluble dolomite beds. In the upper part of the formation almost all the limestone beds are medium light to medium gray, weathering light gray with conspicuous yellowish-gray to grayish-brown silty to argillaceous laminae. Infrequent varietal types are irregularly mottled partially dolomitized beds, in which the dolo-

mitized material seems to occur in organic burrows, and lenses of co minuted fossil fragment calcarenite at the top of occasional limestone be Similar limestones also are common in the lower part of the formatic but light gray to nearly white limestones, in which most laminations a parently reflect grain-size variations with conspicuous concentrations f noncarbonate clastics in the laminae usually not developed, become abu dant and sometimes dominate exposures. In places these beds look su ciently like the high-calcium Annville Formation to have caused soi confusion in the early stages of mapping. Other beds have a distin pinkish cast similar to some beds in the Buffalo Springs Formation. Th gross aspect of the lower Epler Formation in many places is quite simi to that of the Buffalo Springs Formation, and the two are most read distinguished by the greater quartz silt content of the older formatio At least two and probably more zones 1 to 6 feet thick carrying abo 10 percent disseminated coarse quartz sand grains occur in the lower p of the formation. Sparse nodular chert is present only near the base Dauphin County but is more general and abundant to the east.

Limits.—Mapping criteria for the base of the Epler Formation in Da phin County were given in discussion of the upper Stonehenge Formati contact. This contact is poorly exposed. In Lebanon County (Geyer a others, 1958; Gray and others, 1958) the basal Epler is more dolom than the middle portion and gradational to the underlying Rickenba Dolomite. The Epler Formation as a whole seems less dolomitic in Daup County; no trend to increasing dolomite content was noted in the lo part but might have escaped notice under the poor exposure conditions It seems quite reasonable, however, that this trend would not be present the absence of the Rickenbach facies. Rocks above the Cumberland-Val Stonehenge Formation are definitely not more dolomitic than higher the section. The top of the Epler Formation in the Berks County type a is placed at the top of the highest limestone bed in a gradational seque to the dolomites of the overlying Ontelaunee Formation. This lies ab 75 to 100 feet below the base of the lowest chert bed in a dolomite a chert interval that is more than 150 feet thick near the Schuylkill Riv To the west in Lebanon County limestone beds occur closer to the ch and the base of the chert has been picked as the contact for mapp purposes.

The cherty member, however, thins westerly across Lebanon Cou and has been recognized only at a few localities as a single thin bed nodule horizon in eastern Dauphin County. The Ontelaunee Formati also contains increasing numbers of limestone interbeds westward fr Berks County, increasing the problem of picking the contact. In the sence of the cherty horizon, the contact has been picked at the point wh dolomite beds first equal limestone beds in thickness and abundance. In

ure 4. Overturned contact of Epler and Ontelaunee Formations at Pennsylvania Supply Corp. quarry on Swatara Creek north of Hummelstown. Contact is placed at thin black hert bed in gradational sequence.

andoned quarry and outcrops on the north side of the Hershey Country ub near the cold storage plant, a chert-nodule horizon believed to rep- ent the basal Ontelaunee Formation chert is exposed about at the 50-50 estone-to-dolomite level; and the transition from limestone with sub- dinate dolomite interbeds to dolomites with subordinate limestone inter- ds is accomplished through a fairly small interval.

Exposure.—The Epler Formation is well exposed in steep banks and ffs along the left bank of Swatara Creek almost everywhere that the eek crosses the crop area. Elsewhere there are a number of scattered

exposures, except in the lowest portion adjacent to the Stonehenge F mation; a few merit mention. There is a very large Bethlehem Steel Co pany quarry at Steelton on the Susquehanna River where an unusua dolomitic zone has been selectively quarried for magnesian flux. Both t northern and southern contacts of the Epler Formation are faulted here the stratigraphic position of the dolomitic zone in the lower Epler is u known. The upper part of the formation is well exposed just north of t fork of U.S. 322 and U.S. 422 in an abandoned quarry and road cut, a is described in the Appendix as locality 7. Fairly numerous exposur mostly from the middle part of the formation occur near Spring Cre between the clubhouse of the Hershey Golf Course and the Hershey Cou try Club, passing through the amusement park and zoo.

Age and correlation of the post-Stonehenge Beekmantown strata v be considered after all have been described.

Ontelaunee Formation

Name.—Hobson (1957) designated the upper dolomitic part of t Beekmantown Group in Berks County the Ontelaunee Formation fr exposures along the Schuylkill River in Ontelaunee Township.

Distribution.—The southwesternmost exposure of the Ontelaunee F mation is near the inactive quarry 0.8 miles south of the covered bric at Fiddler's Elbow on North Union Street, Lower Swatara Townsh Dauphin County. South of this quarry the Ontelaunee Formation has be overthrust by the Epler Formation and is not recognized in the Steelt belt, though it is possible that slivers adjacent to the Annville Formati may be locally present but unrecognizable in the prevailing conditions minimal exposure. Northeastward from the Lower Swatara exposures t Ontelaunee Formation is present across the eastern two-thirds of Daupl County and all of Lebanon County. Structural complications and lo unconformity in western Berks County sporadically interrupt the cor nuity of the central Berks County type area. Hobson (1963) locally rec nizes probable Ontelaunee Formation as far east as Northampton, l A. A. Drake (cf. MacKenzie, *in* Ryan, 1961) maps, Hobson (1963) c curring, Epler Formation as the uppermost Beekmantown in the east Lehigh Valley.

Dolomite and limestone near the east end of the Harrisburg-Rutherf belt (Cumberland Valley sequence) were tentatively identified by Hobs (1963) as Ontelaunee and Annville Formation lithologies but are sho by the present mapping to lie within the St. Paul Group.

The Ontelaunee Formation has also been mapped by D. U. Wise a his students at Franklin and Marshall College in the northern part of L caster County south of the Triassic basin.

Thickness.—In Dauphin County two sections have been measured ross the Ontelaunee Formation. About 600 feet is indicated north of mmelstown (Locality 6 of Appendix) and 800 feet near the Lebanon nty line (Locality 9). A major part of the formation is covered in h sections. In view of the known thrusting above and within the On- unee Formation at Fiddler's Elbow, which may well extend as far as Hummelstown locality, it is possible that the Hummelstown section be structurally thinned. Comparable shearing is not evident at the ion northeast of Hershey but minor folding impressed on the gener- uniform dip might well lead to an excessive measured thickness. In v of these relations the southwestward thinning implied by the measure- nts may not be real. To a first order of approximation, a compromise re of 700 feet is perhaps best representative of the thickness of the elaunee Formation in Dauphin County.

Northeast of Dauphin County, Hobson (1963) reports 767 to 800 feet Ontelaunee Formation in central Lebanon County and 675 feet where y developed in Berks County.

Character.—The Ontelaunee Formation is divisible into two members Dauphin County. The upper member was first recognized in Lebanon nty by Gray (1952a), and Hobson (1963) recognizes 70 feet north- of Hershey (Locality 9) and 40 feet at Fiddler's Elbow (Locality 5). the latter section the upper contact is thrust and the full original thick- s is presumably not present. This member is characterized by medium- k-gray, micro-crystalline to very finely crystalline, heavy- to very heavy 5 foot)-bedded, yellowish-gray-weathering dolomite with black shale tings between beds sometimes showing stylolitic structure. Chemical lyses from this member show the bulk composition to be a notably e dolomite.

The main body below the upper member is composed of heavy interbeds dolomite and limestone; approximately 60 to 80 percent is dolomite. e dolomites are medium to medium dark gray, generally a little lighter n the upper member dolomite but darker than the associated limestones. ey weather yellowish gray and appear generally similar to the upper mber, but laminations tend to be a little more distinct. The limestone s are medium gray, finely crystalline, and weather medium light gray, n with distinct laminations reflecting detectable compositional varia- ns. The terrigenous clastic-bearing laminae characteristic of the Epler rmation limestones are very rarely developed. A few beds of limestone ttled by secondary dolomitization, apparently in organic burrowings, l beds of very light-gray, very pure limestone, have been observed as e varietal lithologies. Almost all beds fall in the range 1 to 4½ feet h the majority averaging 2 to 2½ feet in thickness. A little dark-gray

chert is locally found at the base of the formation but does not consti the conspicuous marker it forms further to the east.

Eastward across Lebanon County the proportion of limestone beds creases somewhat, and a basal cherty member becomes distinguisha In Berks County the upper pure dark dolomite member is absent. I apparently younger than any of the beds recognized at the type sect

Limits.—The lower contact of the Ontelaunee Formation is descri in detail in the discussion of the upper contact of the Epler Format In Dauphin County it is essentially the level at which an interbedded quence with predominant dolomite succeeds one with predominant li stone.

In Dauphin and Lebanon Counties Ontelaunee Formation is over by the high-calcium Annville Formation. The contact is a frequent lc of shearing, but adjacent beds seem to be strictly parallel where not stu turally disturbed. This contact is said to be an unconformity (Gray, 195 Prouty, 1959; Hobson, 1963) based on a presumed interval of nonde sition. Numerous excellent exposures of the contact are afforded by large quarries in the Annville Limestone. Nothing known to the autho these exposures suggests an unconformity by the physical relationsl except the abrupt change in lithology. As beds lithically indistinguisha from parts of the Annville Limestone and of remarkable purity (0.1 cent insoluble residue in one sample) are occasionally interbedded v dolomites of the Ontelaunee Formation, the lithic contrast obviously n have little temporal significance.

In Berks County the Annville Formation and the upper pure dolor member of the Ontelaunee Formation are absent east of Womelsdorf. top of the Beekmantown Group in this area is a clear unconformity considerable relief, locally cutting out the entire Ontelaunee Format The existence of this unconformity, however, has no necessary relati ship to a possible Ontelaunee-Annville disconformity to the west. known features preclude correlation with the unquestioned post-Ann diastem.

Exposures.—The Ontelaunee Formation is usually well exposed on banks of Swatara Creek where it crosses the outcrop belt. Elsewhere the county natural exposure is quite limited, though scattered small crops are less infrequent than in the lower part of the section. The up member is well exposed in the hanging walls of the Annville Limest quarries.

Age and Correlation.—Several lines of evidence suggest the upper of the Ontelaunee Formation may be of lower Chazyan age, hence your than usually considered Beekmantown elsewhere. The argument en

sideration of the top of the Cumberland-Valley-sequence Beekman-
n Group and is treated in a following section.

Rockdale Run Formation

he Rockdale Run Formation has not been identified in Dauphin County
igh a small part may be included in the narrow strip mapped as Pines-
g Station Dolomite in the Harrisburg-Rutherford belt. An isolated ex-
ire does occur just across the Susquehanna River from Harrisburg.
following description is included to facilitate structural and strati-
hic discussion.

Name.—Sando (1956) gave the name Rockdale Run Formation to in-
edded limestones and dolomites lying between the Stonehenge Lime-
e and the Pinesburg Station Dolomite from exposures along Rockdale
, Washington County, Maryland.

Distribution and Thickness.—An isolated exposure of a partial section
ound at the Susquehanna River. The main outcrop belt is cut at its
heast end by the Yellow Breeches thrust near Bowmansdale, about 3
s west of the isolated crops. Southwest of Bowmansdale the Rockdale
Formation is continuous throughout the Cumberland Valley. Sando
58) measured 2547 feet near Chambersburg in a section lacking the
ermost part. This suggests a slight thickening northward from the
yland type area where 2345 to 2555 feet were present in complete
ions (Sando, 1957). As mentioned in the general discussion of the
nberland-Valley Beekmantown Group, reliable thicknesses are not
lable northeast of Chambersburg. Stose's (1953) 2000-foot figure is
inimum, and 2500 feet seems structurally plausible in the Carlisle quad-
gle. A comparable thickness in the deep structure of Dauphin County
nplied.

Character.—The lower two-thirds of the Rockdale Run Formation is
racterized by silty detrital limestones and algal limestones. The detrital
stones are substantially identical to the typical silty laminated lime-
es of the Epler Formation except recrystallization has not obscured
original clastic textures of the carbonate detritus. The algal limestones
uently have well-developed stromatolites. They have no known equiva-
in the Lebanon Valley sequence. Dolomites and dolomitic limestones
rbedded with the dominant rocks form less than 10 percent of the sec-
at Chambersburg. Sandy zones comparable to those in the lower part
he Epler Formation are present in the lower half of the Rockdale Run
mation. While too poorly developed for mapping, sand content is ap-
ntly higher than in the comparable Epler Formation beds; and actu-
forms a calcareous sandstone in the Chambersburg section (Sando,
8).

Lithotypes in the upper third of the formation are generally simila the lower part but in greatly different proportions. Laminated primar early diagenetic dolomites predominate; and, with mottled replacei dolomites, form up to 80 percent of the section. The interbedded l stones include some pure massive limestones (0.5 to 2.8 percent insol residue) which seem to be represented by comparable beds in the C launee Formation.

Several kinds of chert are abundant in the southern Cumberland Va The stratigraphically restricted silicified cryptozoon horizon was m tioned in discussion of the Stonehenge contact. It seems to be late persistent though perhaps not as well developed to the northeast. Noc cherts, usually dark though also brown and milky, are common throug the formation without demonstrated concentrations. Comparison of San section descriptions at Chambersburg (1958) and in Maryland (1 seems to confirm my impression that they decrease in abundance to northeast. Irregular masses of milky chert, sometimes forming cauliflo like rosettes, is most common in, though not restricted to, dolomite and is accordingly concentrated in the upper part. This chert is depo discordantly to bedding and apparently developed during or after regi fracturing. Mapping presently in progress by the Pennsylvania Geol Survey in Franklin County demonstrates abundant chert of this type not extend to the northeast.

Limits.—The lower contact of the Rockdale Run Formation is ma by the first appearance of dolomite interbeds in a limestone sequenc is more fully discussed in description of the upper Stonehenge contac

The top of the formation is placed at the top of the highest limes bed beneath the entirely dolomitic Pinesburg Station Dolomite. This tact falls in a zone of secondary dolomitization. The stratigraphic varies at least 20 feet and probably more.

Age and Correlation.—Sando (1957) established four faunal zone the Rockdale Run Formation type area, which he (1958) also recogn at Chambersburg. The lower three zones lie in the dominantly limy l part. They were correlated with the Roubidoux to Powell Formation the North American standard section. The top zone lies at least 330 below the top of the formation in the dolomitic member. It is tentati correlated with the Smithville Formation of the standard section. Lac recent studies makes precise faunal correlations with the central Penn vania section difficult. In general terms, the two lower zones are Nit Dolomite equivalents, the third zone has at least one species very clos an Axeman Limestone form, and the upper zone appears to be represe in the Bellefonte Dolomite.

Discussion of correlation with the Lebanon Valley sequence is defe to a subsequent section.

Pinesburg Station Dolomite

'ame.—Sando (1956) designated the uppermost dolomites of the Cum-and-Valley Beekmantown-Group Pinesburg Station Dolomite from ex-ıres near Pinesburg Station, Washington County, Maryland.

)istribution and Thickness.—About 500 feet of dolomite is present near Potomac River, but it is shown to thin northward by mapping in prog- in Franklin County. The unit is structurally absent in the vicinity of do's (1958) Chambersburg study, but 50 to 100 feet of dolomite have ı recognized above typical exposures of the upper Rockdale Run For-ion at a number of points to the northeast. The unit is believed to be ent above the Rockdale Run Formation throughout the Cumberland ley. It has been tentatively identified in the main Cumberland Valley belt of the Beekmantown Group at Mechanicsburg, about 8 miles t of Dauphin County.

An isolated narrow band of Beekmantown Group dolomite lying beneath St. Paul Group in the Harrisburg-Rutherford belt is here mapped as esburg Station Dolomite though uppermost Rockdale Run Formation be represented.

Character.—In the type area (Sando, 1957) the dolomites of the Pines-g Station Formation are identical to those described in the Rockdale ı Formation, from which it is distinguished only by the absence of estone. Laminated primary or early diagenetic dolomites compose about percent of the formation and the remainder is mottled replacement omites. Irregular white chert like that in the upper Rockdale Run For-ion is especially abundant in the lower half of the Pinesburg Station omite. This chert is not persistent to the northeast, however.

n Dauphin County very limited exposures show 1- to 4½-foot beds of dium-gray, medium-grained dolomite weathering grayish yellow with inct laminae in part. No chert was observed. Limestone interbeds were ed in several places quite close to the inferred contact with the St. Paul oup. They had the general appearance of Beekmantown limestones and therefore, possibly referable to the Rockdale Run Formation; but they ht also represent a possible gradation to the St. Paul Group. They do make a mappable unit under the poor exposure conditions. In view of relatively small thickness of strata exposed in the belt and their posi-immediately subjacent to the St. Paul Group it was considered appro-ıte to map all of the Beekmantown Group exposed in the Harrisburg-therford belt as Pinesburg Station Dolomite.

Limits.—The lower contact of Pinesburg Station Dolomite is grada-ıal to the Rockdale Run Formation by the appearance of limestone rbeds. It is treated in more detail in discussion of the Rockdale Run

Formation. This contact may be present but is not mappable in Dau
County.

Sando (1956, 1957) places the top of the Pinesburg Station Dolo
at the base of the first limestone bed in the Row Park Limestone as s
fied as the top of the Beekmantown by Neuman (1951). Both aut
concur in describing the contact as obscure, at varying stratigraphic l
controlled by local variations in dolomitization, and apparently gradati
Sando (1957) suggests the stratigraphic variability of this horizon ma
as much as 100 feet.

A disconformity is recognized at this level to the southwest (E
1940; Bridge, 1955). A similar disconformity may exist in the northea
part of the Cumberland Valley, as it is suggested (Cooper, and Co
1946; Swartz, 1948) that the overlying St. Paul Group thins near the
quehanna River by progressive deletion of basal beds (overlap). In
of the great thickness of the St. Paul Group reported at Carlisle (S
1953) and the apparent persistence of the Pinesburg Station Dolo
the effect of such disconformity, if present, is small. The contact has
been examined in detail in the northeastern Cumberland Valley and
presently uncertain whether it is transitional or disconformable in Cun
land and Dauphin Counties.

No exposure of the contact was recognized in the Harrisburg-Ru
ford belt.

Exposures.—The trace of the Pinesburg Station Dolomite in Dau
County is almost entirely concealed by slopewash from the adjacent sl
A natural outcrop is known in Paxtang about 200 yards north of I
Street on the Cameron Parkway. Shale crops out within 20 feet nor
the dolomite in the footwall of the Paxtang thrust. Several exposures
in cuts along the main line of the Reading Railroad east from Harris
approximately between 18th and 31st Streets.

Age and Correlation.—No fossils have been found in the Pines
Station Dolomite. Contacts are apparently gradational to both the u
lying Rockdale Run Formation which has Late Canadian Smithvill
fauna, last exposed 330 feet below the base of the Pinesburg Station D
mite, (Sando, 1957) and the overlying Row Park Limestone (Lowe
Paul Group) which has a middle Chazyan fauna (Neuman, 1951)
the basis of this relationship Sando (1957) tentatively correlates the v
undated interval with the upper part of the Bellefonte Dolomite of c
Pennsylvania and the uppermost Lower Ordovician Black Rock and
mor of the standard section. He indicates the Chazy-Canadian bou
probably lies somewhere within the Pinesburg Station Dolomite. G
pods and cephalopods of uncertain exact age but Lower Ordovician a
are found in the upper Rockdale Run Formation, but nothing prec

possibility that the entire Pinesburg Station Formation might be of er Chazyan age.

Correlation of Beekmantown Group in Cumberland and Lebanon Valley Sequences

here is an obvious close similarity in gross lithic sequence between the kmantown Group of Lebanon Valley sequence as expressed in Dauphin nty and the Beekmantown Group in the Cumberland Valley sequence. re is a basal limestone (Stonehenge) gradational to limestone with ordinate dolomite interbeds (Epler-lower Rockdale Run) gradational n interbedded sequence with dolomite predominant (lower Ontelaunee-er Rockdale Run) gradational to an upper dolomite (upper Ontelaunee-Pinesburg Station). Thicknesses of corresponding units are not identical but are very much of the same order. Substantial differences in lithologic detail reflect the tectonic discontinuity between the sequences; but, n reference to observed variation along strike, these differences are entirely consistent with a displacement across strike of units having depositional continuity.

Evidence for precise faunal correlation is sparse but tends to confirm correlation by gross lithology. Ophiletid gastropods occur in both the afferstown Member and Hobson's (1953) middle member of Stouffers-n-type lithology of the Stonehenge Formation and confirm its Lower lovician age. *Finkelnburgia* sp. from the thin upper Stonehenge Formation of Berks County may be equivalent to one of the species in the *Bellerophon* Zone of the upper Stonehenge Formation in Franklin County, but s not suffice to fix position within the upper member at Chambersburg. nce it provides no evidence on the suspected Stonehenge age of the ossiliferous Rickenbach Formation. Another *Finkelnburgia* species from lowermost Epler Formation of Berks County, however, was tentatively ntified by Sando (in Hobson, 1963) with the *Lecanospira* Zone in the er Rockdale Run Formation. If this correlation is correct, the lower er Formation of Berks County is equivalent to the lower Rockdale Run mation; and Rickenbach must grade out southwesterly into the Stonege Formation only, as previously inferred from thickness relationships. aunule including diparelasmoid brachiopods from near the top of the er Formation apparently represents the *Diparelasma* Zone which is the d faunizone of the Rockdale Run Formation, occurring just below the er dolomitic member. *Hormotoma* (?) sp. has been identified in the er Ontelaunee Formation of Berks County (equivalent to the upper t of the lower interbedded member in Dauphin County). This genus vide ranging and would have little correlation value on a fine scale ept that the only known occurrences in the Cumberland-Valley Beekntown Group are in the *Syntrophopsis-Clelandoceras* Zone of the upper

dolomitic member of the Rockdale Run Formation. These faunal corr
tions, though based on unprecise or tentative identifications, suggest
Epler Formation is correlative to the lower calcareous Rockdale Run;
the lower interbedded Ontelaunee is correlative, at least in part, with
upper dolomitic Rockdale Run Formation, as suggested by the litho
similarities.

Two somewhat problematical occurrences of *Maclurites magnus* are
ported from the uppermost Beekmantown of Berks County and the
high Valley. Hobson (1963) illustrates a specimen found in a limest
float block near a dolomite-Martinsburg Formation fault (?) contact
West Reading. The dolomite is certainly Beekmantown but not defini
identified as Ontelaunee Formation, and the relation of the limestone b
to the dolomite is uncertain.

Maclurites magnus is also reported from the Annville Limestone
Lebanon County (Stose and Jonas, 1927), and it is possible that his
mation might be represented by some remnants below the unconfor
separating the Beekmantown Group in this area from Trentonian ro
The Lehigh Valley occurrences are inferred to be valid by Willard (19
They are based on old reports which are not verifiable save by the as-
unaccomplished rediscovery of specimens *in situ*.

If the *Maclurites* are correctly identified and do in fact come from
upper Beekmantown Group, Chazyan age of the upper pure dolomite m
ber of the Ontelaunee Formation seems virtually certain. At present
probable lower Chazyan age of this member rests on the lithic correla
with the Pinesburg Station Dolomite and its position above strata co
lative with the *Syntrophopsis-Clelandoceras* Zone.

Hobson (1963) has suggested a different correlation based prima
on the assumption of the inter-sequence persistence of synchronous c
zones. In Berks County he observed two stratigraphically restricted z
of very abundant nodular and bedded chert, one in the upper Rickenb
and the other near the base of the Ontelaunee Formation. He correl
these chert zones with the silicified cryptozoon zone at the base of the R
dale Run Formation and the zone of especially abundant irregular w
chert in the lower half of the Pinesburg Station Dolomite in the soutl
Cumberland Valley.

This correlation is open to several objections. It assumes that the
related cherts are all primary or early diagenetic deposits reflecting spe
intervals during which the depositional environment, presumably as a
sult of special chemical conditions in the sea water, was especially c
dusive to silica deposition. It further assumes that these special envi
mental conditions were regionally prevalent over 200 miles from cer
Berks County to northern Virginia; or, if more local, they were contro
by a common factor giving simultaneous chert formation in especially

rable locations. It is my opinion that the observable relations support either of these assumptions over the required distance.

The author concurs in Hobson's reasoning and conclusion that the prominent cherty horizons of the eastern Lebanon Valley are early diagenetic and partially synchronous. It is obvious that the 15-inch bed containing some nodular chert at the base of the Ontelaunee Formation near Hershey does not represent the same time span as the 150-foot cherty zone of the lower Ontelaunee in a comparably thick section on the Schuylkill River. General stratigraphic considerations, however, indicate that initiation of chert deposition was about simultaneous in the two areas and across Lebanon County, but it persisted for increasing time to the northeast. Time relationships are more obscure in the lower cherty zone. In Berks County the exposed Stonehenge Formation has no chert. Chert first appears as nodules and stringers in the lower Rickenbach about 275 feet above the base of the Stonehenge Formation. Conspicuous development of bedded chert starts about 600 feet above the same datum and is scattered through about 130 feet. In central Lebanon County, Geyer and others (1958) and Gray and others (1958) say simply that chert lenses and stringers are "present" throughout the Stonehenge Formation and "common" throughout the Rickenbach Formation. Hobson's (1963) section at Richland, however, shows the lowest chert in the Stonehenge Formation at 273 feet above the base, and about 100 feet including less well developed bedded chert in a thinner Rickenbach section, almost lacking the lower member, beginning about 740 feet above the same datum. In view of the probable greater rate of Stonehenge sedimentation compared to that of the Rickenbach, as indicated by sedimentological considerations and thickness relationships, both the onset and maximum of chert development seem to be approximately synchronous. The southwestward diminution of chert content seems to be through a gradational area that remained approximately stationary through time.

Similar considerations indicate probable synchronous development throughout the cryptozoon chert horizon of the Rockdale Run Formation. The environmental conditions, however, were not identical to those governing chert deposition in the Lebanon Valley. The cryptozoons themselves indicate certain environmental conditions that were not apparently present at this level in the Lebanon Valley, as they are not found there above the Cambrian. The silicification of the cryptozoons was a selective partial replacement accompanying dolomitization. This process seems somewhat different from that producing nodules and stringers of chert. Thus there are two different areas of chert formation, having different conditions at the depositional interface, and producing different kinds of chert. In this case it would seem that simultaneity of deposition in the two areas is a proposition that must be proved rather than presumed.

There is some indication that they are, in fact, not quite the same ag in the two sequences. Both lie in an interval between the upper Stoneheng *Bellefontia* Zone and the lower Rockdale Run *Lecanospira* Zone and thei putative correlatives. On the other hand, in Dauphin County, while chert i very rare, it is more common in the upper Stonehenge than at any othe horizon. In view of the lateral gradation from Rickenbach to Stoneheng lithology it seems probable that this chert represents the southwesternmos extension of the upper Rickenbach Formation cherts. There is no indica tion of comparable gradation of Rickenbach chert into the Epler Forma tion. If the Epler-Stonehenge contact in Dauphin County is in fact the sam as the Rockdale Run-Stonehenge contact, it is apparent that the chert of th Rickenbach Formation must be slightly older than the cryptozoon chert o the Rockdale Run Formation. The two cherts might be simultaneous if th top of the Stonehenge Formation in Dauphin County was a laterally grada tional equivalent of the lowest part of the Epler Formation above th Rickenbach in Lebanon County; but the fact that the Epler thicken southwesterly at a rate about proportional to the thickening of the entir Beekmantown Group suggests that this is unlikely.

The correlation of the upper chert zone in the two sequences is sub ject to considerably stronger objections. Hobson cited a zone of darl blocky chert float above the portion of the Rockdale Run Formatio measured by Sando (1958) at Chambersburg. He explicitly identifies i with the cauliflower chert (irregular white chert of Sando, 1957) zone i the lower Pinesburg Station Dolomite, though he did not observe thi characteristic lithology. According to Sando the dark nodular cherts of th Rockdale Run Formation, presumably including the material observed b Hobson, are apparently early diagenetic, but they occur throughout th formation without stratigraphic regularity. The irregular white chert which form the cherty zone of the lower Pinesburg Station Dolomite, how ever, are secondary cherts, discordantly emplaced in detail, and apparentl formed after regional fracturing. Their stratigraphic concentration is ap parently the result of the fact that they are preferentially, though no exclusively, developed in dolomites which are much more abundant at th stratigraphic level at which the cherts form a conspicuous float. As thi chert is not an early diagenetic type, it would seem, in any case to hav little time correlation value.

The cauliflower chert is a useful lithostratigraphic marker within it area of occurrence because its distribution is lithologically controlled. A it is largely or entirely confined in the southern part of the Cumberlan Valley, however, it lacks continuity with, or genetic relation to, the bedde cherts of the lower Ontelaunee.

In addition to the fact that the cherts are demonstrably not correla tive by common genesis, Hobson's faunal data suggest they are not th

ame age despite his assertion to the contrary. In Berks County the basal ntelaunee chert zone lies not far above the faunule probably correlative ith the *Diplarelasma* Zone near the top of the lower calcareous mem- er of the Rockdale Run Formation and well below the *Hormotoma* (?) ccurrence possibly correlative with the *Syntrophopsis-Clelandoceras* Zone n the upper dolomite member of the Rockdale Run. The conspicuous auliflower chert zone of the southern Cumberland Valley, on the other and, is best developed more than 300 feet above the highest identifiable lements of the *Syntrophopsis-Clelandoceras* Zone, and over 1000 feet bove the top of the *Diplarelasma* Zone. Even allowing for the tentative ature of the faunal correlations, the considerable difference in the po- tion of the two cherts with respect to the faunas seem to preclude their me equivalence.

Summary.—In view of the foregoing objections to use of the cherts as atum horizons for intersequence correlation, the correlations proposed y Hobson (1963) are rejected. The correlation claimed in this report on ne basis of the gross similarity of the lithic sequences in the Lebanon Valley sequence of Dauphin County and the Cumberland Valley sequence, s confirmed by the limited faunal data, differs from Hobson's in the fol- owing particulars.

1. The Stonehenge-Rockdale Run contact is thought to be the same ge as the contact of the Epler Formation with the laterally gradational Stonehenge-Rickenbach Formations. Hobson's correlation of the Ricken- ach and Rockdale Run cherts would make this contact slightly younger n the Lebanon Valley.

2. The Epler Formation is correlated only with the lower calcareous nember *(Lecanospira, Archaeoscyphia,* and *Diplarelasma* Zones) of the Rockdale Run Formation. Hobson correlates the Epler with the entire Rockdale Run Formation.

3. The upper dolomite member *(Syntrophopsis-Clelandoceras* Zone and overlying barren strata) of the Rockdale Run Formation is correlated with he lower interbedded member of the Ontelaunee Formation. Hobson correlated the lower Ontelaunee with the Pinesburg Station Dolomite.

4. The Pinesburg Station Dolomite is correlated with the upper pure dolomite member of the Ontelaunee Formation, and both are thought to be largely or entirely of lower Chazyan age. Hobson suggests that the upper Ontelaunee is the lateral equivalent of middle Chazyan limestones lower part of St. Paul Group) in the Cumberland Valley. This suggestion arises from tentative identification of Ontelaunee stratigraphically over- ying Annville at the east end of the Harrisburg-Rutherford belt (Hobson, 1963, sect. 24). Re-examination of Hobson's section indicates that both ithologies are typical of, and interbedded in, the St. Paul Group as ex-

pressed in this area; and the apparent sequence observed by Hobson ha no particular significance. These rocks differ in lithic details and insolubl residue from the suggested formational identification. The disproportionat thickness of the Ontelaunee Formation with respect to the Pinesburg Sta tion Dolomite apparently influenced him to think that the upper Onte launee might be younger than the Pinesburg Station Dolomite. Correla tion of only the upper Ontelaunee with the Pinesburg Station Dolomit removes this disproportion.

Significance of the Lower-Middle Ordovician Boundary

It has been indicated several times in the preceding discussion that ther appears to be, at most, no substantial disconformity between the Beek mantown Group and the overlying units in the Cumberland Valley an in the Lebanon Valley west of Womelsdorf. An important disconformit is widely recognized in the Appalachian area at this level, however, a summarized by Bridge (1955). Despite the absence of obvious interrup tion of deposition in Dauphin County and adjacent areas, the boundar marks major change through the entire region.

Prior to the Middle Ordovician, the entire Paleozoic sequence in thi area was deposited under conditions of regionally extensive uniformity Disconformities such as inferred below the Beekmantown Group at th Delaware River indicate that subsidence and deposition were not entirel constant away from the centers of thickest accumulation; but the char acter of the sediments indicates general tectonic stability.

The Middle Ordovician presents a substantially different aspect. Gen eral subsidence was halted at the end of the Canadian Epoch and else where areas were subject to erosion. As subsidence resumed to permi renewed accumulation, an irregular pattern of isolated or partially isolate basins appeared with local peculiarities of lithology and fauna that ha produced great confusion in stratigraphic studies. The initial deposits i most instances were limestones not too dissimilar from the underlyin rocks; but an increasing proportion of terrigenous clastics is added durin the Middle Ordovician until ultimately shales overlie the thick carbonat sequence. Tectonism, as reflected by folding and angular unconformities was not active in the Dauphin County area, nor elsewhere in the know extent of the miogeosyncline, at this time; but the changing character o the sediments indicates active tectonism in the eugeosynclinal belt to th southeast. The Lower-Middle Ordovician boundary conditions represen remote indications of the onset of tectonic instability in the eugeosyncline that culminated in the upper Middle and Upper Ordovician flysch and sub stantial deformation in this area.

Local subsidence apparently continued, or was only briefly interrupted, across the Lower-Middle Ordovician boundary in the Great Valley from a

ast Womelsdorf to northern Virginia, but the thickness and character the post-Beekmantown sediments is much more variable than in the der rocks. The correlation between the two sequences is accordingly ore tenuous.

Chazyan Series (Lower-Middle Ordovician)

Upper Ontelaunee Formation and Pinesburg Station Dolomite

The Ontelaunee Formation and the Pinesburg Station Dolomite are included in the Beekmantown Group as defined in the Cumberland and Lebanon Valleys. Full consideration of these formations is given in the preceding section on the Beekmantown Group, in which it is indicated that the upper pure dolomite member of the Ontelaunee Formation and an definite portion, perhaps all, of the Pinesburg Station are probably of wer Chazyan age.

St. Paul Group

Name.—Neuman (1951) proposed the name St. Paul Group* for the ocks previously called "Stones River" (Stose, 1906) in the Cumberland alley on the basis of Ulrich's (Ulrich and Schuchert, 1902) correlation to ie type Stones River Limestone of Tennessee (Safford, 1851). Subsequent work (Cooper and Prouty, 1943; Cooper, 1945) has shown that ie "Stones River" of the Great Valley is neither continuous nor synronous with that of the type area, and a new name is indicated.

The name St. Paul Group comes from the type section near St. Paul's hurch, Washington County, Maryland in the area of the Cumberland alley Beekmantown Group type sections. The St. Paul Group is specied as being bounded at the base by the Beekmantown Group, and at the op by the Chambersburg Formation (or the Lincolnshire Limestone, here present). In the type area it is composed of the New Market Lime-

* The name St. Paul's Group for the Lower Ordovician graptolite-bearing shales f northwestern Newfoundland (Johnson, 1941) has priority and technically prohibits euman's (1951) use according to Art. 11 (c) of the Stratigraphic Code [Art. 7 (f) nd art. 9 of 1933 Stratigraphic Code (Ashley and others, 1933) applicable at the me of naming]. The U. S. Geological Survey was cognizant of the name in both sages but had formally used neither as of 1955 (Wilson and others, 1957). G. V. ohee (personal communication) states that the United States Geological Survey onsiders the name available for use in the sense of Neuman without objection, nce the Survey does not recognize the rule of precedence for minor units geographially remote from the borders of the United States. While it is unfortunate the uplication occurred, it is clear that the name should be retained under Art. 11 (a) f the Stratigraphic Code; the name has been well established, having been used y at least five authors other than the proposer. The Newfoundland usage apparently has little currency and is annotated in the Ordovician correlation table Twenhofel, 1954) as "not adequately defined."

stone (Cooper and Cooper, 1946) above and the Row Park Limeston (Neuman, 1951) below. These formations are not readily identified b lithologic criteria in Pennsylvania, where a threefold lithologic division c the "Stones River" was recognized by Stose (1909) and subsequent worke (Bassler, 1919, Cooper and Cooper, 1946; and Prouty in Gates, 1960).

Prouty (*in* Gates, 1960) doubts the advisability of extending the term S Paul Group into the northeastern Cumberland Valley on the grounds tha the threefold subdivision evidently most applicable differs from the sub division in the type area, though he recognized the equivalency of th strata. Art. 9 (a) of the Stratigraphic Code, however, recognizes that th formational content of a group may change geographically, and the geolc gic names committee of the Pennsylvania Geologic Survey adopted S Paul Group as a welcome substitute for "Stones River" on the State Geolc gic Map (Gray, Shepps, and others, 1960) for the rocks between th Beekmantown Group and the Chambersburg Formation.

Distribution and Thickness.—The distribution of the St. Paul Group i Dauphin County, as mapped in this report, agrees substantially with tha shown on the Geologic Map of Pennsylvania (Gray, Shepps, and other 1960) and includes a considerable thickness of beds called transitional t the Beekmantown by Prouty (*in* Gates, 1960). This mapping differs fro the interpretation shown on the state map in that the Annville Formatio is not a separately recognizable unit in the Harrisburg-Rutherford belt, an much of the "Hershey-Myerstown" of the Harrisburg-Rutherford belt o the state map is here questionably referred to the St. Paul Group.

The south side of the outcrop belt in Dauphin and eastern Cumberlan Counties is marked by the Yellow Breeches thrust. The width of the ou crop belt increases westward across the county from the eastern limit c exposure; but it is not significant of stratigraphic thickness, which is nc readily determined from available exposures. A thickness probably i excess of 1000 feet is indicated on the west side of the Susquehann River (locality 2 of Appendix) and is indicative of the thickness in Dau phin County.

Southwestward from Dauphin County the St. Paul Group is present i length of Cumberland Valley and has been mapped in northern Virgini and northeastern West Virginia. The unit thickens rapidly northeasterl from the southern limit of mapping. It is only 90 feet thick at Kernstow Virginia, about 35 miles southwest of the Potomac River, 377 feet thic at the Potomac in Maryland, and as much as 1400 feet thick 11 mile northeast of the Potomac in southern Franklin County (Neuman, 1951) The thicknesses are not well established through the rest of the Penn sylvania Cumberland Valley. Stose (1909) reports a thickness on the orde of 1000 feet in the Chambersburg area and from 1000 to 1700 feet i

e Carlisle quadrangle (1953). Prouty (*in* Gates, 1960) reports about 680 et along the Turnpike near the Carlisle exit; but the base is not clearly fined, and no "transitional" strata such as compose about 375 feet of e Lemoyne section were measured. In the balance, Stose's minimum and reasonable allowance for transitional beds below Prouty's section sug- st an average thickness of about 1000 feet in the Carlisle area, and nce throughout the northwestern Cumberland Valley from the Susque- nna River to Chambersburg. Older interpretations (e.g. Bassler, 1919, 120) indicated that the "Stones River Limestone" thinned northwester- by overlap losing a progressively larger portion of the lower beds. This terpretation rested on the assumption that the transitional beds were ekmantown, whereas, in fact, they appear to be laterally gradational cies of the lower St. Paul Group with an essentially constant total inter- l preserved.

Character.—In Dauphin County the St. Paul Group consists of heavy- dded limestones irregularly bedded with dolomites which form about a arter of the section. As shown in the Lemoyne quarries sections (locali- s 2 and 2a of Appendix), there is no significant stratigraphic concen- ation of the dolomite beds. Near the Carlisle exit of the Pennsylvania urnpike (section 3 of Prouty, *in* Gates, 1960) a 170-foot, dolomite-free terval of Prouty's lower St. Paul member separates dolomitic beds higher the section from dolomites in the "transitional" beds below. In Dauphin ounty, however, only a middle (sparingly) cherty member is possibly appable by lithologic criteria; the St. Paul Group members and under- ing transitional beds discriminated by Prouty do not appear to be readily stinguishable.

The predominant lithology in Dauphin County is heavy-bedded, me- um- to medium-dark-gray, fine-grained limestones showing little or no pparent lamination on a fresh surface but weathering medium-light-gray ith distinct regular lamination to irregular mottling of yellowish-, brown- h-, or olive-gray-weathering terrigenous and magnesian material. A few presentative beds are individually described in the short section in the utherford Freight Yards (locality 4 of Appendix). They are distinguished om the typical limestones of the Epler Formation, which they closely semble in gross aspect, by the absence of metamorphic recrystallization nd a slightly lower chroma of the weathered laminae. The olive-gray eathering color of some laminae, moreover, seems to be unique to the t. Paul Group, whereas the distinctly orangish gray brown common in the pler does not seem to be represented.

Dolomites appear to be generally similar in Dauphin County regard- ss of the formation in which they occur. On a fresh surface they are pparently crystalline and structureless, and usually darker than asso- iated limestones. On weathering they are not infrequently distinctly lam-

Figure 5. St. Paul Group beds exposed just south of west approach to South Bridge. No irregular dark-weathering lamination in limestone bed under compass, incipient boudina in dolomite bed above.

inated and have a yellowish cast. On the whole, the dolomites of th Pinesburg Station Dolomite and the St. Paul Group tend to be more di tinctly laminated than those in the Lebanon Valley sequence and som times appear coarser grained. The weathered surface of St. Paul dolomit is creamy rather than the distinct yellow to occasionally orangish cast the older dolomites. It is impossible however, to discriminate betwe specimens from any formation with confidence.

Nodular to discontinuously bedded chert is confined to a distinct zo in the upper half of the section at Lemoyne. Similar cherts are observe at several exposures in Dauphin County and presumably represent th same interval. This chert is not sufficiently abundant to leave any co spicuous trace in the overlying soil; but in Dauphin County, cherts prev lent in the Lebanon Valley sequence further northeast approach th abundance of the St. Paul cherts only in the upper Stonehenge Form tion.

Heavy-bedded to massive, medium-to medium-light-gray, very ligh gray-weathering, fine-grained, pure-looking limestones, often showing di tinct fine lamination in relief on the weathered surface, are a subordina but conspicuous element. These occur interbedded with more characteri

St. Paul Group lithologies and are not stratigraphically concentrated to a mappable zone ("Annville Formation" of the Harrisburg-Rutherford belt) as inferred by Prouty (1959) and shown on the State Geologic Map. The wide stratigraphic range of high purity limestones is shown in the Lemoyne quarries (locality 2a of the Appendix). The occurrence of these beds is by no means unique to the St. Paul Group. As previously noted, the upper Ontelaunee and lower Epler Formations have similar beds. A single insoluble residue determination from the exposure east of Spring Creek on U. S. Highway 322, specifically identified as lower Annville by Prouty (1959, p. 8), yielded 2.7 percent residue of quartz silt and minor carbonaceous material. This is quite comparable to results obtained from some of the pure-looking beds of the Epler Formation but unlike the extremely fine carbonaceous residues obtained from the Annville and upper Ontelaunee Formations.

Upper St. Paul Group (?) of thrust plate.—At many places on the south side of the Harrisburg-Rutherford belt, rocks typical of the St. Paul Group in Dauphin County, as described above, are overridden by a thrust slice of dark limestone probably nowhere more than 100 feet thick. These limestones are heavy bedded to massive but strongly sheared and lineated parallel to the bedding throughout giving a somewhat shaly appearance to fresh fractures. The weathered surface shows alternation of coarse medium-light-gray and yellowish-gray laminae. Only a little recognizable dolomite is associated with these beds.

These rocks were formerly called cement rock ("Leesport") by Stose (Stose and Jonas, 1927; Stose and Ljundstedt, 1931) and Hershey Formation by Prouty (1959) and on the State Geologic Map (Gray, Shepps, and others, 1960). Stose (1950), however, correctly recognized they were involved in thrusting on the south side of the Harrisburg-Rutherford belt and not in depositional continuity with the underlying rocks. They are not remotely similar to any other rocks called Hershey except in their relatively dark color and the somewhat shaly aspect imparted by shearing. The weathered beds, where not disintegrating into platy or chippy fragments along the cleavage, closely resemble the more regularly laminated limestone beds in the rocks considered to be definitely in the St. Paul Group. Smear lineation similar to, but less intense than, that in the thrust plate is sometimes developed in the underlying rocks near the thrust and increases the resemblance. Insoluble residues from these rocks have a distinct character unlike anything else encountered and are notably different from Hershey Formation samples. They are light gray, abundantly silty and apparently devoid of carbonaceous material. The tectonic position of these rocks makes it probable that they represent some portion of the Cumberland Valley sequence that has been caught in a slice at the sole of the Yellow Breeches thrust. On the basis of some gross simi-

larity to the St. Paul Group beds previously mentioned, and possibl correlation by chemical criteria (discussed in a later section), these rock are tentatively assigned to the upper St. Paul Group. The most plausibl alternative assignment is to the Chambersburg Formation which thes rocks somewhat resemble in some gross aspects of lithology and compos tion, but which differ greatly in bedding characteristics and weathering As normal development of the Chambersburg lithology is unknown i Dauphin County, additional structural complications might have to b postulated to support this interpretation.

As it is obvious from the structural position of these rocks that the were deposited some distance southeast of their present exposure, th simple fact that the lithology does not exactly correspond to any recog nized in either the autochthon or the main thrust sheet is, itself, hardl remarkable. The differences between the two main sequences is a re flection of lateral change normal to the present strike. It is thus probabl that the lithologic peculiarities of these rocks are the result of depositio in an environment transitional between those concurrently effective at th depositional sites of the Cumberland and Lebanon Valley sequences. Th anomalous factor is that the distinctive features of these rocks do no obviously fit into an orderly facies transition between correlative units i the two main sequences. The correct explanation is, perhaps, that at th time these rocks were deposited the environment in the accumulation are of the Lebanon Valley sequence was one of nondeposition, that is, tha the rocks of the Osp (?) slice were deposited on the flank of the depo sitional basin at a time a diastem was forming in the Lebanon Valley This proposition is entirely consistent with assigning an upper St. Pau Group age to these rocks as the established unconformity above th Annville Limestone almost certainly includes at least part of the uppe Chazyan as well as Black River time.

Limits.—As described in discussion of the Pinesburg Station Dolomite the lower St. Paul Group is laterally and vertically gradational to th top of the Beekmantown Group. The upper stratigraphic contact is no exposed in Dauphin County, but a regional disconformity representing a depositional hiatus in the Cumberland Valley and adjacent areas is inter preted by most workers.

Exposure.—Natural exposure through most of the area is severely lim ited not only by the general soluble character of the carbonates but alsc by exceptionally thick overburden from other sources including slope wash from escarpments of the Martinsburg Formation on both sides of the nar row outcrop belt, Pleistocene alluvial terraces, artificial fill, and the struc tures, streets, and landscaping of the Harrisburg area. Artificial exposures however, are frequent. Almost all of the structural readings on the accom

nying map were made in the numerous highway and railway cuts and bandoned quarries. The best exposure, however, is provided by the uarries and railway cuts immediately across the Susquehanna River from auphin County, described as locality 2 in the Appendix, where a nearly ntinuous section is available.

Rocks of the thrust sheet were until recently well exposed in a ridge n the south side of Paxton Avenue about ¼ mile east of the county ison but have now been quarried away. The best available exposures ay still be found in the graded area just to the south and in sev- al small abandoned quarries south of Chamber Hill Road, east of Eisen- ower Boulevard behind the industrial buildings.

The window exposed through the shales of the Yellow Breeches thrust neet in the upper part of the Laurel Run valley is crossed by Streit's Road its northeastern end. The presence of limestone is indicated only by oat fragments which yield insoluble residues mostly like those charac- ristic of the upper St. Paul Group (?) of the lowest thrust slice; but a few e more like samples of the definite St. Paul.

Age and Correlation.—Chazyan age of the St. Paul Group on the basis its contained fauna has been recognized since the earliest work of Stose. ecent work (Neuman, 1951; Cooper, 1956) restricts it to middle and pper Chazyan. Typical St. Paul fossils are recognized in the Lemoyne ction by Prouty (*in* Gates, 1960) and large gastropods reported as *Maclurites magnus* may be found occasionally at a number of locations ithin the Harrisburg-Rutherford belt. The best specimens observed by ne author are near the entrance of a small quarry at the extreme east nd of the belt. They are exposed in cross section on weathered surfaces nd are not readily removed from the rock.

The Loysburg Formation of central Pennsylvania has been considered quivalent to the St. Paul Group since its conception by Collie (1903) who rst introduced the confusion with type Stones River Limestone into the ppalachian area. This correlation is still considered generally correct, nd present views of the relationship are summarized by Wagner (1963).

Annville Formation

Name.—The Annville Formation was given formal status by Prouty 1959) from its development in the Annville quarry district of Lebanon County. The trade term Annville Stone had long been used for the quarry roduct and "Annville limestone" in apparently formational sense but ithout formal definition appears in several geologic references to the nnville district. It was indicated as needing formational definition by routy in 1951, and demonstrated as being a mappable unit clearly dis- inct from the Beekmantown Group by Gray (1952a).

Distribution and Thickness.—The Annville Formation is generally pre ent above the Beekmantown Group throughout the Lebanon Valley fro Steelton on the Susquehanna River to Womelsdorf in western Berk County. Local discontinuities in the outcrop belt reflect structural compl cations. It has also been recognized at the north edge of the Lancaste County carbonate belt and in the Oley Valley of southeastern Berk County. In the Lebanon Valley its distribution is essentially identical t that of the upper pure dolomite member of the Ontelaunee Formatio

The Annville Formation is about 250 feet thick in the Annville di trict and across most of Lebanon County but thins to the northeast an southwest. It is 180 feet thick at the type section near the Lebanon Count line (locality 9 of Appendix) and 133 feet thick in the Swatara distric just west of Hershey (locality 8 of Appendix). There is evidence of cor siderable shearing along both contacts in this area and throughout muc of the Lebanon Valley; but movement seems to have been parallel to th stratification, and this amount of southwestward thinning could largel be the result of original stratigraphic conditions rather than tectonic Southwest of the tear fault at Hummelstown, however, the Annville-Onte launee contact is a well-defined thrust fault that clearly truncates beddin and in places cuts the Annville out entirely. The Annville-Myerstow contact is likewise a distinct thrust fault in most exposures. In the bel from Swatara Creek to Steelton the Epler Formation is thrust against th Annville Formation with the Ontelaunee Formation entirely cut out Under these conditions it is obvious that the 78 feet at Fiddler's Elbo (locality 5 of Appendix) and 29 feet at Steelton (locality 3 of Appendix do not represent depositional thicknesses. Most of the thrust faults ap parently display movement quite close to the average bedding, so that i is possible that little section is lost; but it is impossible to evaluate th contribution made to total thinning by any southwestward trend of initia stratigraphic thinning.

Character.—The Annville Formation is characterized by thick-bedde to massive, light- to medium-dark-gray, finely crystalline to sometime coarsely crystalline, high calcium limestone, which weathers to very light gray, smooth or fluted surfaces with alternate fine laminae weatherin more deeply. As indicated by detailed section descriptions of the Appendi and the bore hole analyses of the chemical composition section, individua beds may have somewhat less than high calcium purity; but all bul analyses are high grade.

Very light-gray to white crystalline beds "mottled" or "streaked" wit medium- to medium-dark-gray are described by both Gray (1952a) an Prouty (1959) as a persistent feature of the basal part of the formation Such beds are certainly present at a number of locations in Dauphi

ɔunty, both where the Ontelaunee-Annville contact is apparently con-
ɾrdant and where it is obviously thrust. On the other hand, there are
so many places where they have not been perceived. In the occurrences
was able to examine carefully in situ, it was apparent that the darker
ɔrtions of the rock were bean-shaped lentiles to long stringers parallel to
ɪear lineations in the general area. In view of the obvious recrystalliza-
ɔn and tectonic orientation in these rocks, I consider that this lithology
a tectonic facies produced by recrystallization under shear and has no
ɪrticular stratigraphic significance except that it tends to occur at the
ɔmpetence contrast between the limestone and dolomites. Its presence
ɐar the thrust fault, as in locality 5 of the Appendix, does not neces-
rily represent the stratigraphic base of the formation. On the other
ɪnd its presence adjacent to apparently concordant contacts may be in-
cative of substantial movement on this locus.

Limits.—The lower contact of the Annville Formation has already been
scussed in some detail in consideration of the Ontelaunee Formation.
he contact was said to be disconformable by Gray (1952a) and Prouty

gure 6. Inverted sequence, upper Ontelaunee Formation in hanging wall above portals, quarry development in Annville Limestone, stripped base of Myerstown Formation forms footwall. West pit of the H. E. Millard Co., Palmyra plant. This structure is typical of Annville belt.

(1951, 1959) but is apparently concordant where not obviously thru There is no evidence of any erosional relief on the underlying Ontelaun Formation which apparently always has the upper pure dolomite memb where the Annville is present in the Lebanon Valley. The essential reas for inferring an unconformity was a lower and middle Chazyan hiatus ir plied by the correlations understood by Gray and Prouty. Subseque work, discussed with respect to the age of the upper Beekmantown co tact and below in regard to the age of the Annville Formation, fails demonstrate the need for such a disconformity. On the other hand, ge graphic distribution, low terrigenous clastic content, and rare high ca cium limestone beds in the upper Ontelaunee Formation show a close r lation between these two formations. For these reasons the Annville believed to have been initially conformable on the Beekmantown Grou

The upper contact of the Annville Formation with the Myerstown Fo mation does seem to be disconformable, as beds of Black River age a not represented. The lower Myerstown is carbonaceous and everywhe has been a locus of slippage that effectively obliterates any evidence of th original depositional nature of the contact.

Exposures.—Owing to its purity and consequent high solubility, th trace of the Annville is marked by a virtual absence of outcrop or eve

Figure 7. Typical outcrop of Annville Limestone near H. E. Millard Co., Palmyra quarries.

entifiable float except near Swatara Creek, where some natural exposure curs. The formation is best studied, however, in the numerous quarries hich expose the whole thickness. The localities with measured sections the Annville Formation given in the Appendix offer representative ac-ssible exposures.

Age and Correlation.—Chazyan age of the Annville Formation is es-blished by a single reported occurrence of *Maclurites mangus* (Stose and nas, 1927), its comparable position in the stratigraphic sequence to e definitely middle and upper Chazyan St. Paul Group of the Cumber-nd Valley sequence, and, by the interpretation of this report, its con-rmable contact with the Beekmantown Group, which is thought to in-ude beds of lower Chazyan age.

Prouty (1959) interpreted certain pure recrystallized limestone beds the St. Paul Group in the Harrisburg-Rutherford belt as representing e Annville Formation lying on rocks of the middle member of the St. aul Group. As mentioned in description of the St. Paul Group, detailed apping does not support this interpretation. I can find no stratigraphic structural evidence that would indicate or permit correlation of the nnville Formation to any particular part of the St. Paul Group, though eir general equivalence seems certain.

Contrary to finding evidences of gradation from the St. Paul Group to e Annville Formation, I consider these two units to provide the clear-t demonstration that the facies change along strike within the autoch-onous Cumberland Valley sequence is not directly convergent on the cie shown at the southwest end of the allochthonous Lebanon Valley quence. It is readily apparent that the whole St. Paul Group becomes ore magnesian and generally somewhat less pure from the southern umberland Valley to the Susquehanna River section. Furthermore, it ems to remain fairly close to about a 1000-foot thickness from the hambersburg area to the northeastern unit of exposure if the transitional eds above the predominantly dolomitic Beekmantown Group are included. his is in striking contrast to the 250-foot maximum of pure limestone nly, found less than a mile from the beds of the same age showing an ncreasingly dolomitic trend along strike.

Changes of the type shown northeastward in the Cumberland Valley re commonly associated with restricted circulation and approach to the dge of a depositional basin. The Annville Formation on the other hand, ows a minimum terrigenous influence and any gradation from the north-rn Cumberland Valley to the site of Annville deposition must have been ffshore, considerably to the east of the regional strike.

Hiatus

In the Great Valley northeast of the Susquehanna River, Black Rive rocks are unknown, and northeast of Womelsdorf, Chazyan rocks a also absent or very sparingly represented. In the Cumberland Valley t lower part of the Chambersburg Formation (Shippensburg Formation Craig, 1941, 1949) is Black River but is supposed to cut out disco formably below the upper part of the Chambersburg (Mercersburg Fo mation of Craig) toward the Susquehanna River (Prouty, 1959). A di conformity between lower Chambersburg and the St. Paul Group in soutl ern Pennsylvania and Maryland is also inferred by Craig (1949) an Neuman (1952, 1960) but pre-Black River and post-Black River hiatus merge into a single upper Chazyan-lower Trentonian disconformity in t northeastern Cumberland Valley. On a regional scale, the magnitude this disconformity increases along the Great Valley from southern Pen sylvania to a maximum in central Berks County. In the latter area erosion relief on the Beekmantown Group is at least several hundred feet, and t base of the succeeding Trentonian Jacksonburg Formation is apparent younger than its base in the New Jersey type area. Gray (1952b) indicat that part of the erosional relief on the Beekmantown in this area may b the result of erosion subsequent to deposition of the Jacksonburg Form tion, but he does not suppose that this is the major erosional interval.

Trentonian Series

Myerstown Formation

Name.—According to Prouty (1959),

> The Myerstown Limestone was named from exposures in the general vicinity Myerstown, Lebanon County, Pennsylvania. The type section, however, was chos from exposures in and adjacent to the quarry (George Ebersole and Sons) 1.8 mil southwest of Hummelstown, Pennsylvania, where the Hummelstown-Middletov road crosses Swatara Creek (locality 5 of Appendix). Despite the faulting and fol ing observed in this quarry, it is believed that the Myerstown has not been involv in faulting that would eliminate any part of the section.

The choice of type section is unfortunate in that new exposure does n support the inference that a structurally uncomplicated full section of t formation as mapped in Lebanon and Berks Counties (Gray and othe 1954, 1958; Geyer and others; 1958, 1963) is present; the general aspe is of a somewhat different facies than the Lebanon and Berks County e posures. There is no question that the Myerstown is a valid mappab unit where the term has been applied west of the Schuylkill River, b exposures in the Myerstown-Millardsville area are much more represent tive of the typical development of the formation than is the type sectio It is suggested that the apparently complete, though discontinuously e

ed, section starting at the Annville Limestone in the abandoned H. E. llard quarry at Millardsville (Prouty, 1959, section 5) and continuing road cuts along the road from Millardsville to U. S. Highway 422 to Hershey Formation conglomerate should be considered the standard erence section for typical development of the Myerstown Formation. is section has the particular advantage for a reference standard that st of the forms of the sparse Myerstown fauna have been described y from this location.

Distribution.—Except where locally absent by structural complications, Myerstown Formation forms a continuous belt through the Lebanon lley from the Susquehanna River to Womelsdorf in western Berks unty. It is essentially coextensive with the Annville Limestone and is o found in the Lancaster County carbonate area south of the Triassic sin.

On the map accompanying this report the Myerstown has not been ferentiated from the overlying Hershey Formation through most of the crop belt in Dauphin County. The Myerstown is present throughout the a mapped as Hershey-Myerstown undifferentiated, and it may actually stitute the entire width of the belt through much of the mapped area. wever, owing to structural complications, poor exposure, and absence the characteristic Myerstown float fragments which disappear in a ies change across westernmost Lebanon and Dauphin Counties, the sence or absence of some beds of Lebanon-County-lithology Hershey rmation is hard to establish.

Throughout most of Dauphin County the limestones of the Lebanon lley sequence are certainly or inferentially thrust upon the subjacent les, although the latter are definitely part of the allochthonous sequence the west and probably also in the east. The absence of the Myerstown rmation north of Hummelstown is clearly the result of this thrust which y have an even greater influence on the distribution of the Hershey rmation.

Thickness.—The thickness of the Myerstown Formation shows consid- ble local tectonic variation, and the original stratigraphic thickness is rd to establish precisely. In central Lebanon County (Geyer and others, 58; Gray and others, 1958) the normal thickness seems to be about 0 feet. The relative importance of structural and stratigraphic effects its disappearance to the northeast is unknown. The thickest reported tion is at Steelton (locality 3 of Appendix) near the southwestern limit exposure where Prouty (1959) measured 385 feet; but this thickness is nost certainly excessive by repetition in the thick largely covered zone Prouty's section, as the 233 feet between the upper and lower meta- ntonites is an unreasonably larger proportion of the total section than

the interval between the highest and lowest metabentonites elsewhere c served, and recent exposures show imbricate thrusting above and belo Near the Lebanon-Dauphin County line extensive drilling on the form Annville Stone Company property (now Hershey Estates) shows cc siderable tectonic variation in thickness (Geyer, 1956), but the appro mately 215 feet of Myerstown shown in Geyer's cross section seems to fairly representative. Between these localities 216 feet were measured w of Hershey (locality 8) and 56 feet at the Fiddler's Elbow type section (l cality 5). Both sections are structurally complicated and the latter is c tainly incomplete. As far as can be determined the original thickness pro ably changes little from central Lebanon County and was probably b tween 200 and 250 feet throughout Dauphin County.

Character.—The Myerstown Formation is predominantly a thin, reg larly bedded, medium-dark- to dark-gray, fine-grained, dense limestor which weathers medium to medium light gray with a distinct bluish cast. Lebanon County the trace of the outcrop is usually marked by smooth rounded plates of dense, ringing limestone, often with a distincti "chicken track" network weathered on the bedding surface. Float of th character is less abundant in eastern Dauphin County and is rarely reco nized to the west, apparently owing to somewhat increased shaliness the limestone beds. Very thin dark shale beds interbedded with the lim stones are sometimes present and seem to become increasingly abunda toward the west edge of the county. Fossil fragmental calcarenite beds le than a foot thick have been recognized in a number of localities.

The basal beds are shaly looking, very dark and carbonaceous. Th are always strongly sheared with abundant development of shiny, blac carbonaceous slickensides. Despite their shaly appearance they tend to purer than the formation as a whole. Quarry operators report that the beds always run better than 85 percent and often better than 90 perce $CaCO_3$.

Four beds of pale-yellowish-orange- to light-olive-gray-weathered, regular-textured, somewhat phyllitic shale 1¼ to 8 inches thick were fo merly observable within about 50 stratigraphic feet in the upper half the Myerstown Formation in the gutter beside the road north of the Pa myra quarry section (locality 9 of Appendix.) In a fresh sample encou tered in a drill core nearby, the rock is medium-light- to light-gray, ve fine-grained, very finely laminated, with crinkly sericitic partings and small percentage of finely disseminated pyrite showing some selective co centration in particular groups of laminae. These beds are very widely di tributed, though all four beds are only rarely identifiable in a single e posure. The lateral persistence of these beds and their anomalous cha acter in the limestone sequence supports the assertion that they are met bentonites (altered volcanic ash falls). Similar metabentonites occur in th

ne general stratigraphic interval over a wide area beyond the Lebanon lley and are considered to represent superior synchronous datum planes stratigraphic correlation.

Fragments of white "columnar" quartz (fragments of regularly interstallized quartz-calcite veins from which the calcite has been dissolved) re recognized by Prouty (1959) as a generally useful surficial marker the trace of the Myerstown Formation. He indicates this kind of float present from the Martinsburg Formation to the Annville Limestone, but ims a conspicuous concentration over the Myerstown. Gray (1952) indites that "columnar" quartz is commonly associated with Myerstown at in Lebanon County, but it has not proved a useful marker in Dauin County. The occurrence of occasional columnar quartz float fragnts is confined to the part of the section above the Beekmantown Group, indicated by Prouty; but locally significant concentrations occur only er the Martinsburg Formation in Dauphin County. Veins of the parent aterial have been observed in the Martinsburg and in the upper St. Paul oup (?) but not in the Myerstown Formation.

Limits.—The lower contact of the Myerstown Formation presents a arp, easily recognized contrast with the conspicuously pure massive nestone of the underlying Annville. Exposures of this contact commonly ow bedding parallel in the two units, but there is invariably evidence substantial shearing in the Myerstown near the contact arising from e competence contrast between the units. Owing to this deformation nall primary structures, which might provide some indication of the disnformity between these units inferred from stratigraphic relationships, e not preserved.

The lower conglomerate member of the overlying Hershey Formation ovides a satisfactory top to the Myerstown Formation for mapping purses where it is developed in the eastern Lebanon Valley. Elsewhere, owever, the Myerstown is apparently gradational into the shalier Hershey Formation; and, in the absence of good exposure, the contact is not adily defined. At least in some locations where the conglomerate is esent the deposition of the shaly Hershey lithology was initiated before e conglomerate formed, and in no case is there clear evidence of eron at the top of the Myerstown. The conglomerate fragments are not Myerstown derivation.

Exposure.—Good exposure of the lower Myerstown Formation is found and near the foot wall of all the Annville Limestone quarries. Other nall outcrops and exposures are sparsely scattered through the map area. readily accessible outcrop, rather better than most, and fairly representave of the formation as mapped in Dauphin County, is located just south the Hershey by-pass and just east of Spring Creek in the Hershey Golf ourse grounds.

Age and Correlation.—Six Middle Ordovician fossil forms includi two uniquely Trentonian species have been described by Prouty (195 from the Millardsville reference section. Several specimens of a *Praspo* type bryozoan, but probably not the typical "Oranda"—Jacksonburg *simulatrix,* var. *orientalis,* have been found quite close to the Annvi Limestone contact at the west end of the Swatara quarries (locality 8 Appendix). Bryozoans of this type including *P. simulatrix* proper are t only unfragmented fossil material other than crinoid columnals describ from the Myerstown Formation except at the Millardsville section.

On the basis of common forms and physical similarity to more fossilif ous strata in nearby areas, Prouty concludes that the Myerstown is prc ably equivalent to the upper Rockland and Kirkfield of the New Yc standard section. He considers it to be correlative to the upper part the Mercersburg (Upper Chambersburg) Formation and the lower p of the "Oranda" Formation of the Cumberland Valley sequence and e actly equivalent to the "cement limestone" facies (Miller, 1937) of t Jacksonburg Formation (Kummel, 1909). While the present work d agrees with certain details of the physical correlation with the Jacksc burg Formation, which will be considered after description of the He shey Formation, the age assignment is not substantially affected.

Hershey Formation

Name.—The name Hershey Formation for impure shaly limestones, places with a "basal" dolomite conglomerate, lying between the Mye town and Martinsburg Formations was formally proposed by Prou (1959). The formal definition, however, includes rocks not included the term as previously employed by several other authors (Gray, 1952 1952b; Gray and others, 1954, 1958; Geyer and others, 1958) on t basis of Prouty's (1951) informal proposal. To preserve the establish usage and the integrity of the formation as a mappable unit, it is propos to restrict the name of the lithologies so mapped to Lebanon and weste Berks Counties (Gray and others, 1954, 1958; Geyer and others, 195 1963; Meisler, 1963). The reference area for this usage is the scatter exposures along and near the road between Womelsdorf and Host in we ern Berks County. No good, nearly-continuous section of this formatio which is invariably poorly exposed, can be recommended.

Prouty proposed to extend the names Hershey and Myerstown into tl Lehigh Valley as formal equivalents for the "cement rock" and "ceme limestone" facies (Miller, 1937) of the Jacksonburg Formation (Kumm 1908), and they are so shown on the State Geologic Map (Gray, Shepp and others, 1961). While the general, though not precise, equivalence these units is unquestioned, as discussed in the correlation section, tl substitution of the Lebanon Valley terminology in the Lehigh Valley f

te entrenched usage of Jacksonburg Formation is a questionable improvement. Pending possible refinement from work presently in progress i Berks County, it is proposed to limit the use of Hershey Formation in estern Berks County to those areas where the Myerstown Formation (and Hershey conglomerate) are present, and retain the name Jacksonburg Formation in those areas where the "cement rock" facies directly overlies the Beekmantown Group. The demarcation line between these two distinctly ifferent occurrences approximately, though not precisely, coincides with te Schuylkill River and represents a real structural and stratigraphic discontinuity.

While it is not a convenient field mapping criterion, it is noteworthy hat rock chemically suitable for cement manufacture extends west at last to Evansville, nearly at the western limit of the Jacksonburg Formation as here defined; whereas, all of the Hershey Formation is too magnesian for this use. In view of the close association of the Jacksonburg with cement production in both eastern Pennsylvania and New Jersey, the chemical difference, even though quite subtle, appears to be a legitimate adjunct criterion for lateral discrimination between the Hershey and Jacksonburg Formations.

It is entirely explicit in Prouty's 1959 paper that the name Hershey as intended to apply to impure carbonaceous and shaly limestones lying beneath the Martinsburg Formation, these rocks being supposed to be exactly equivalent to the "cement rock" facies of the Jacksonburg Formation in the Lehigh Valley. It is generally agreed that these rocks are younger than the base of the Martinsburg Formation as mapped at its type area and in the Cumberland Valley (Miller, 1937; Craig, 1949; Swartz, 1948); but they are distinguished from the Martinsburg Formation by being predominantly carbonate. Calcareous black shales and some limestone overlying the "Oranda" of Craig (1949) have always been considered Martinsburg in the Cumberland Valley since Stose's (1909) original work nd are so considered by Prouty. That these shales are at least in part entical in age to fossiliferous Jacksonburg of the New Jersey type area well established by abundant faunal evidence. As Prouty did not propose to include the Cumberland Valley calcareous Martinsburg equivants of the Jacksonburg Formation in the Hershey Formation, it is obious that the carbonate content is the essential diagnostic feature of the rtually nonfossiliferous Hershey Formation.

Several of the Dauphin County Hershey Formation localities given by routy, including the type section (locality 5 of Appendix), however, are artly or entirely composed of partly calcareous dark shales and siltstones. While it is possible that these partly calcareous rocks are lateral equivants of those in the Cumberland Valley and to the Jacksonburg "cement ock," owing to the extreme structural complexity and the appearance of

lithologies not present in the simpler structures of the typical Cumbe land Valley Martinsburg, it is impossible to demonstrate this relation ship; and there is some indication that these rocks are allochthonous an older than the basal Martinsburg of normal Great Valley sections (Plat *in* Carswell and Hollowell, ms.). In Dauphin County the partly calcareou shales are found sporadically across a large part of the Martinsburg cro belt but are often absent adjacent to the carbonate sequence. There i considerable reason to doubt that all occurrences represent the same hor zon, and it cannot be safely assumed that they represent Jacksonbur equivalents. In any event it seems undesirable to include these calcareou shales in the Hershey Formation, whether or not they are temporal equiva lents, as the formation thereby tends to loose its identity as a mappabl lithic entity.

The Hershey Formation, as defined above and used in this report, ha only very limited exposure in the Hershey area and is possibly repre sented by only a few feet at Prouty's (1959) type section. In view of thes facts, renaming the unit mapped in Lebanon and Berks Counties wa considered. It was concluded, however, that the Hershey Formation ha been consistently used as a mapping term and was established in the sens of Art. 11(a) of the Stratigraphic Code. It should, therefore, be pre served with the understanding that the lithology so mapped is that foun in the Womelsdorf-Host reference area.

Character.—As used in this report, the Hershey Formation consists pr marily of dark- to very dark-gray, impure, shaly, and sometimes conspic uously carbonaceous limestone. It is usually strongly cleaved with origina bedding not apparent. Bedding is occasionally defined by thin, impur microcrystalline limestone interbeds and rare noncalcareous black sha laminae. The outcrop weathers medium gray to yellowish gray or ligl olive gray. Float from this lithology consists of light-olive-gray to mode ate-yellowish-brown, quite porous shaly chips which are sometimes entirel leached of calcite, though larger fragments frequently have a darker, ca careous core. Both the fresh and weathered aspect of this rock is ver similar to certain dark shales, both calcareous and noncalcareous, in th Martinsburg Formation. The two can usually be distinguished, howeve by the fact that the partings of the Martinsburg shales usually have a di tinct micaceous phyllitic surface which is not known in the Hershey Fo mation. Carbonaceous films on sheared surfaces in the Hershey ofte look much like the phyllitic partings in the Martinsburg, but, unlike th Martinsburg partings, produce a dark dirty smear on the fingers.

In Berks and Lebanon Counties occasional dense limestone interbe sometimes give rise to platy float fragments looking very much like th Myerstown float of that area but distinguished from it by greater angulari

d not ringing when struck with a hammer. In Dauphin County the pical" Myerstown rounded, ringing, float plates are rare. The characistic Myerstown float is more angular and looks very much like the estone plates sometimes found in the Hershey float in Lebanon Coun- It is possible that partial facies convergence of the two formations is a nificant factor contributing to the very limited exposure of Hershey lithgy in Dauphin County; though, on a regional basis it would be anticited that the Hershey would thin essentially by lateral gradation into a artinsburg Formation lithology.

A conglomerate of subrounded to subangular pebbles and cobbles of lomite and subordinate limestone in an argillaceous lime matrix is found several points in a slice within the Yellow Breeches thrust zone. The urce of the pebbles is unknown though it must not have been far reoved from the locus of deposition. All fragments appear to be of Beekantown lithologies with the stratigraphically underlying Myerstown Foration not represented. A much greater volume of very similar conglomate is found in the lower part of the Hershey Formation in western rks and eastern Lebanon Counties, though portions of the unit differtiated as the conglomerate member by Gray (1951) are only sparsely nglomeratic with thinly scattered clasts. The eastern conglomerate body es not extend westward along strike beyond the Myerstown area; but it es not seem unreasonable to assume that the exposures of the thrust ne are correlative, though structural complications preclude establishg their stratigraphic position. Reference to this rock as Hershey "basal" nglomerate is permissible as a convenient spatial reference only if no netic connotation is attached to the term. Details of the lithology and stratigraphic occurrence do not support the inference that the conomerate represents the initial deposits of transgression on an erosion rface. The significance of the conglomerate is subsequently discussed consideration of the formation limits.

Distribution and thickness.—The Hershey Formation was apparently posited at the top of the Lebanon Valley carbonate sequence as a estward thinning wedge or gradational facies, which possibly was not posited locally in Dauphin County. The thickest development is in the omelsdorf-Host area where Gray (1951) indicates that as much as 1000 et including perhaps 250 feet of the lower conglomerate member might present. Substantial development of the conglomerate member is esntially limited to western Berks County; it is unknown west of the Mystown area except for a few similar-appearing exposures adjacent to the umberland Valley sequence rocks of the Harrisburg-Rutherford belt in a ice which is probably somewhat displaced with respect to the strike of e normal Lebanon Valley exposures, and possibly in a problematic ocrrence at the type section (locality 5 of Appendix). Gray and others

(1958) indicate that the Hershey is probably about 450 feet thick in th Richland quadrangle; it thins westerly across the Lebanon quadrangl from 350 feet to 200 feet according to Geyer and others (1958). Thes thicknesses are approximations derived from the crop width and inferre structure, but the pronounced westward thinning is undoubtedly real de spite any errors that may occur in the estimates. Extrapolation of thi thickness gradient would indicate that the Hershey would pinch out en tirely along strike somewhere in eastern or central Dauphin County. Suc pinchout may be the principal reason why Hershey lithology is not recog nized in most of the main Lebanon Valley sequence belt in Dauphi County, and the less than 20 feet of possible Hershey at Swatara (localit 8 of Appendix) may be a true stratigraphic thickness. The general absenc of apparent Hershey lithology in most of Dauphin County cannot be clearl attributed entirely to stratigraphic factors, however, as thrusting is definitel present between the carbonates and the underlying shales in some area and is inferentially the usual case. Thus original Hershey, if present, ma have been largely cut out in the thrusting.

As used in this report the Hershey Formation is confined to the Lebano Valley sequence. It has not been recognized in the northern part of th Lancaster Valley where most other units of the Lebanon Valley sequenc have been recently differentiated. With the possible exception of th "cement rock" of the Oley Valley, which seems to represent a Lebano Valley sequence outlier, the easternmost exposure of the Hershey an Myerstown Formations is in a complex slice in the vicinity of Werner ville, Berks County. The nearest exposure of Jacksonburg "cement rock in contact with the Beekmantown Group lies about five miles northeas It is recognized to the west at the top of the carbonate sequence in Leba non County except where tectonically absent. Exposures along the mai strike belt extend into easternmost Dauphin County where they are term nated by faulting. A thin remnant may reappear at Swatara (locality 8 Appendix), but the formation is probably not represented at Fiddler Elbow (locality 5 of Appendix) and is shown to be definitely absent the Susquehanna River by recent extensive exposures at Steelton (localit 3 of Appendix).

North of the main Lebanon Valley strike belt isolated patches of He shey lithology, including patches of conglomerate previously suggested t be correlative with the Berks County occurrence, are included in the Ye low Breeches thrust zone. As the structural geometry of the allochthonou sequence indicates that successively higher slices in the allochthon wer derived from progressively more southeasterly sources, it would appea that this lowest slice had a more northwesterly depositional locus than th carbonates of the main Lebanon Valley sequence strike belt in Dauphi County. This would imply, in turn, that the trend of conglomerate dep

on, and probably of thickest total Hershey accumulation, was westerly northwesterly across the present strike if the conglomerates are indeed ated to the eastern exposures.

The Geologic Map of Pennsylvania (Gray, Shepps, and others, 1960) tains several noteworthy errors in the distribution of the Hershey-erstown interval which might cause confusion if used in conjunction n this report. The map shows an isolated patch of this unit lying within Martinsburg Formation northeast of Harrisburg. Detailed mapping Platt (*in* Carswell and Hollowell, ms.) shows that this area is only of the numerous calcareous patches within the Martinsburg Forma-n. A more conspicuous feature is the large area of Hershey shown in nberland County immediately west of Harrisburg. This feature is a ple compilation error which apparently resulted from division of com-tion responsibility at the shale-limestone contact. Calcareous rocks lie both sides of this area, but the greater part is composed of noncalcar-s Martinsburg shale which was not intended to be included in the shey Formation. The distribution shown in this area on the tectonic o accompanying this report (Plate 1) is much more nearly correct ugh only hasty field checks were made to resolve conflicts in recon-ssance maps from which it was compiled. Finally, the continuous belt wn with adjacent Annville Limestone, on the south side of the Harris-g-Rutherford belt and extending into Cumberland County, is largely ginary. This interpretation is based on the slices of Hershey lithology he sole of the Yellow Breeches thrust previously mentioned and the ner concept of a relatively simple syncline underlying the Steelton of the Martinsburg Formation.

Limits.—As used in this report, the Hershey Formation is underlain the Myerstown Formation everywhere a normal stratigraphic sequence present. Prouty (1959) indicates that a basal dolomite conglomerate usual feature; but, in fact, this lithology seems to be limited to the ern quarter of the belt and isolated exposures in western Dauphin nty. As previously mentioned, the stratigraphic position of the con-nerate in the western exposures is only inferential, but the base of the glomerate is valuable mapping criterion for the base of the Hershey mation where it is present in the eastern portion. In the absence of glomerate, the Hershey-Myerstown contact is marked by a change in ding character and increased influx of argillaceous detritus. This contact ard to distinguish, in part owing to poor exposure, but apparently also a gradational character.

Where the conglomerate is present, at least in some locations, the gra-onal change to the Hershey lithology was initiated prior to deposition ier than rigorously basal. As the conglomerate fragments are apparently kmantown and clearly not from the Myerstown, they cannot have been

derived, in any event, from working the debris on an erosion surface. Th form of the main conglomerate body as a wedge thickening eastward alo strike and the coarse, relatively angular character of the carbonate clas imply that the source was a steep declivity located somewhere not far fro the present limit of exposure. Within the context of what may be deduc of the contemporaneous geologic environment, faulting seems the mo probable cause of this geometry. Extension of this reasoning suggests th the Dauphin County occurrences are comparably related to relatively loc faulting, but here there is no indication where the faults might lie. It seer entirely reasonable that the nearly simultaneous increased clay influ presumably from the remote sources producing shale deposition to t southeast, and the faulting of local highs providing coarse carbonate d tritus are manifestations of a single phase in the developing tectonic i stability of the region. There is no clear evidence, however, that this pha produced disconformity in the Hershey-Myerstown depositional basin.

There is no known exposure of a sedimentary contact between the He shey and Martinsburg Formations. The Martinsburg stands at a substa tially higher elevation than the adjacent limestones, and the contact ar has a thick cover of weathered-shale slope wash. The rare exposur through the overburden all show faulted contacts. By analogy with t Cumberland and Lehigh Valley sequences and the logical progression lithologies it is inferred that the Hershey is vertically as well as latera gradational into the Martinsburg.

Exposure.—The general exposure of the Hershey Formation in Daupl County is very poor. Along the main Lebanon Valley belt there is a sm exposure of the Hershey and Martinsburg Formations in fault contact a cut on the east side of the township road running from the bridge wh state Route 743 crosses Swatara Creek toward Palmyra. This exposu is notable in that it is near the western limit of differentiable Hershey map continuity with the Lebanon County exposures. To the southw of this locality the Hershey is next tentatively identified in float at Swatara quarries (locality 8 of Appendix). Prouty (1959) indicates s eral more exposures of the Hershey Formation to the west along the m strike belt, but these are all essentially of the calcareous shale litholo which is here included in the Martinsburg Formation. The occurrences Steelton (locality 3) and Fiddler's Elbow (locality 5) are described the Appendix. There is no clear suggestion that the Hershey lithology tends west of Swatara in the main belt.

North of the Steelton shale belt the slice in the sole of the Yell Breeches thrust is best exposed behind a new commercial building on northeast side of Cameron Street about 100 yards northwest of Gib Street, Steelton (Borough line). The photograph, Figure 10, shows t area as best exposed prior to the construction. Sporadic occurrences

is zone to the east are now largely recognized by float. Prouty reports o exposures of the conglomerate in this zone. These exposures were not scovered during the present mapping and apparently have been covered removed in the substantial grading and construction in this area since outy examined it. Figure 8 showing one of the exposures is taken from outy (1959). It is an excellent example of this lithology and leaves no ubt about the existence of the conglomerate in this zone despite the esent lack of adequate exposure.

On the north side of the Harrisburg-Rutherford belt the Hershey Formaon is well exposed only by the Harrisburg Cold Storage Warehouse on erryhill Street just north of Cameron Street in Harrisburg. The fault contact between the Hershey and Martinsburg Formations is in a covered terval in the bank cut on the east side of the parking lot east of the ilding. South from this covered interval to the railroad spur leading to e warehouse are shaly limestones; and the conglomerate may be seen ong the track, apparently within the shaly limestone. No contact with e purer carbonates can be observed. The exposure has a fairly uniform nspicuous cleavage foliation, but bedding structures where they can be tected are extremely irregular and complex. An additional exposure of e Hershey Formation in a comparable structural situation occurs west of e Susquehanna River near Wormleysburg (locality 1 of Appendix.)

Figure 8. Dolomite cobble conglomerate of Hershey Formation.

Age and Correlation.—Prouty (1959) concludes that the Hershey Fo mation is Middle Trenton in age, approximately equivalent to Sherma Fall of the New York standard section, though a few feet of older be may be included. This age is based on rare occurrences of *Prasopora simu latrix* a little above the base in the eastern part of the outcrop belt, i position in the stratigraphic column, and elements of lithic similarity the fossiliferous upper Jacksonburg Formation of New Jersey and th rocks in the "Oranda" Formation and the *Sinusites cancellatus* Zone the basal Martinsburg Formation of southern Pennsylvania. Structural di continuities make it more difficult to demonstrate the lateral intergrad tion of these units than Prouty implies, but their general equivalence seen certain.

Relation of Hershey and Myerstown Formations to Jacksonburg Formation

Prouty (1959) states that he considers the Hershey and Myerstown Fo mations to be precisely equivalent to the "cement rock" and "cement lim stone" facies respectively of the Jacksonburg Formation in the Lehi Valley. He proposes to extend these names as formal substitutes for t Jacksonburg subdivisions. This proposal is open to three objections: t precise equivalence is not adequately demonstrated; it attempts to d place an entrenched name which has been consistently used and has wi currency beyond purely scientific circles owing to the economic importan of the unit; and it violates the formal rules of precedence in stratigraph nomenclature. Both from the viewpoint of currency and precedence a from the viewpoint of stratigraphic control and quality of exposure would be much more desirable to extend Lehigh Valley terminology ir the Lebanon Valley than contrariwise; if the precise equivalence of t units is established. The value and validity of the Hershey and Myersto Formations rests, in fact, precisely on their provincial character. The su stance of the enumerated objections is discussed below.

In attempting to establish the precise equivalence of the Lebanon a Lehigh Valley rocks, Prouty asserts the lithic similarity of the rocks w little documentation; but he devotes considerable attention to establish temporal identity. The argument of temporal identity is actually a statem of correlation rather than formational equivalence in the strict lithostra graphic sense.

Viewed as a correlation study Prouty produces good evidence to su port the reasonable conclusion that comparable units in the two ar are generally the same age. His assertion that the Hershey-Myerstown a "cement rock"-"cement limestone" contacts represent the same essentia synchronous regional disconformity is more debatable. As previously in cated, the Hershey-Myerstown contact seems to be laterally gradational a

ay even shift laterally in time. R. L. Miller (1937) drew this inference ncerning the relationship between the "cement rock" and "cement lime- ne" facies. Indeed, his explicit reason for choosing not to employ one the formational designations that had previously been proposed to dif- entiate between these lithologies was that the gradational contact be- een them varied geographically in age.

The case for an unconformity essentially rests on three facts: the un- ubted approximate equivalence in age between the correlated units, e occurrence of a "probable" (Miller, 1937) unconformity between the per and lower Jacksonburg in New Jersey on the basis of a sharp lithic d faunal change, and the occurrence of local conglomerates in both the rshey and in the New Jersey Jacksonburg. The present writer has no rsonal familiarity with the New Jersey occurrences, but the following servations may be made from published descriptions. The disconformity, any, between the upper and lower Jacksonburg of the type section does t represent a very long time span according to the more recent interpre- ions (Miller, 1937; Prouty 1959). Little or no extension of the known atigraphic range of the faunas in the upper and lower members would required to bridge the gap. While it is entirely possible that the abrupt ange in lithology represents withdrawal and readvance of the sea intro- cing a new fauna, it is equally possible than an abrupt influx of more gillaceous detritus drastically changed the ecologic conditions and re- lted in the establishment of an almost entirely new fauna while maintain- g depositional continuity. There is certainly no clear physical evidence disconformity reported at the Jacksonburg type section. The conglome- es reported elsewhere at about this horizon within the New Jersey Jack- nburg are apparently lithically and genetically similar to the Hershey nglomerate. It has already been shown that the Hershey conglomerate is t good evidence for an unconformity. It seems quite possible that the me is true in New Jersey. The presence or absence of a minor uncon- rmity in New Jersey is in any event of doubtful use to correlation if it s no clear equivalent in the Lebanon Valley.

The case against the concept of the Hershey-Myerstown and "cement ck"-"cement limestone" contacts representing a diastrophic time plane sts, however, on more than just the apparent gradational nature of the ntact and the negative evidence. *Prasopora simulatrix* var. *orientalis* oc- rs in the upper part of the Myerstown at Swatara while *Prasopora* is con- ed to the "cement rock" facies of the Lehigh Valley and the upper Jack- nburg Formation of New Jersey, strongly suggesting that the top of the yerstown is younger than the "cement limestone." The same conclusion reached by consideration of the metabentonite horizons. While the iden- y of the metabentonites in the Lebanon and Lehigh Valleys is by no eans demonstrated, it seems highly probable that these occurrences are

correlative and represent the best available physical time markers. Tl metabentonites are confined to the Myerstown but are divided betwe the "cement limestone" and the lower part of the "cement rock."

The fundamental objection to the supposed lithostratigraphic equiv lence of the Hershey Formation and the "cement rock" facies and tl Myerstown Formation and the "cement limestone" facies of the Jackso burg Formation is not, however, that there are still some uncertainties precise time equivalence and correlation. The matter of precise correl tion is questioned in detail only because this argument is the only o that has been substantially developed in proposing the formational ide tity of the units in the Lebanon and Lehigh Valleys. The basic objectic is rather that the lithologic identity and even depositional continuity of t Myerstown Formation and the "cement limestone" facies is by no mea obvious. The closest present exposures of these two units are separate by more than 20 miles in which the "cement rock" facies directly ove lies the Beekmantown Group without any evidence that "cement lim stone" was ever deposited. The Myerstown and "cement limestone" a lithically similar to the extent that they are less argillaceous than the ove lying rocks and generally less magnesian than the older rocks with the e ception of the Annville Formation. There is little resemblance in gro aspect or in some lithologic details, however. The "cement limestone" characteristically very heavy bedded to massive; the predominant litholo is a fossil fragmental calcarenite, often coarsely crystalline, which is qui unlike anything in the Myerstown but a few relatively thin beds. Th most recent study bearing on these rocks (Sherwood, 1964) is not pr marily stratigraphic, but Sherwood specifically states that he has chose to retain the "cement rock"-"cement limestone" terminology in the mai part of the Pennsylvania cement belt on the grounds that he did not reco nize Myerstown lithology therein. In examining the rocks in Berks Count the present author was independently led to the same opinion. The avai able chronostratigraphic evidence indicates that the units are approximatel correlative, but they are lithologically too dissimilar to presume lithostrat graphic identity when evidence of continuity is lacking.

There is a much greater resemblance between the Hershey Formatio and the "cement rock" facies of the Jacksonburg Formation, and it is n unreasonable to apply the same formational designation to both. As th lithology occurs in somewhat different stratigraphic sequences in the Leba non and Lehigh Valleys, however, and as they differ in subtle but econom cally important compositional factors, it seems more convenient to use di tinctive names for these units also.

The fact that Jacksonburg Formation has been applied to the rock yielding raw material by the cement industry is not, in any case, to b

htly regarded, as most of the geologic work done in this area is directly indirectly related to the industry. The terms "cement rock" and "cement nestone" are obviously basically utilization terms which have no formal ologic status. They do, however, correspond to mappable units which e legitimately formational in the sense of the stratigraphic code. It may reasonably held that for scientific purposes it is desirable to establish rmal names for these units and raise the Jacksonburg of the Lehigh Val- to group status; but previous efforts to do so (Wherry, 1909; Miller, 11; Peck, 1911) were not accepted by the cement industry, and the mes proposed are not now in use. The fact remains, however, the terms sky and Nazareth Formations for "cement limestone" and "cement ck" respectively as used by Wherry and Miller were adequately defined d essentially correspond to the "cement rock" and "cement limestone" cies as presently mapped, as by Sherwood (1964) for example. If a for- ational subdivision is to be made of the Jacksonburg in the Lehigh alley it is clear that these names have precedence and should be revived. is especially desirable in this case, as the subdivision in the Lehigh Val- has economic significance, that any proposed subdivision unambigu- sly coincide with the practical quarrying units. This objective is better rved by formations established with reference to the excellent exposures the quarry district than importing recently established names from rocks ore poorly exposed elsewhere.

Comments on the "Leesport Formation" (abandoned)

Stose and Jonas (1927) proposed the name Leesport Formation for lcareous rocks underlying the Martinsburg Shale and overlying the Beek- antown Group, or Chazyan limestones where present, for use in the cinity of the Schuylkill River and westward. They recognized that these cks were in part similar to the Jacksonburg Formation of the Lehigh alley but included lithologies of problematic relationship to the Jackson- rg, and they felt that a new name was warranted for these rocks on the sis that the overall relationship to the Jacksonburg was uncertain.

The type section for the formation was chosen as the exposures in the ilway cut in West Leesport, Berks County. The choice of the type sec- n was unfortunate in that it is structurally complex and contains litho- gies that do not belong in the interval to which the formation was in- nded to refer. This situation led to inconsistency in application of the rm, primarily by confusion with limestone horizons within the Martins- rg Formation. The problems with the "Lcesport Formation" are dis- ssed most extensively by R. L. Miller (1937a and b). The name Lees- rt was used extensively only by Stose, but was perpetuated by a number his publications notably the 1931 state geologic map. Stose himself idently recognized that the term had become unsatisfactory as he refers

simply to "Ordovician cement rock" in his 1946 and subsequent papers o the area.

Prouty (1951, 1959) proposed the names Myerstown and Hershey Fo mations to accommodate that portion of the rocks sometimes called Lee port which did not properly belong in previously established formation It is substantially in this sense that the latter terms have been used in th report, though by the boundary criteria here proposed for distinguishir between the Hershey Formation and the "cement rock" facies of the Jacl sonburg Formation the shaly limestone at the Leesport type section woul be referred to the latter unit.

Chambersburg Formation

The Chambersburg Formation of the Cumberland Valley as define (Stose, 1906) and emended by Stose (1909) was applied to medium- t thin-bedded, cobbly-weathering limestones with Black River and Tren tonian fauna lying between the St. Paul Group ("Stones River") and th Martinsburg Shale. These rocks have a reasonably abundant and divers fauna which can be separated into fairly distinct successional zones. Th situation has given rise to a number of proposed modifications and re finements of Stose's original definition on essentially paleontologic criteri The most recent and current of these is Craig (1949) who divides Stose original Chambersburg Formation into three formations: Shippensbur Mercersburg, and "Oranda" from oldest to youngest.

The Shippensburg-Mercersburg contact represents a disconformity be tween the Black River and Trentonian parts of the section. Apparentl there is an increasing hiatus northeastward from the type area, and Prout (1959) concludes that the older unit disappears entirely by unconformity i the northeastern Cumberland Valley. The type sections of these two uni are taken in the general area of the Marion (Franklin County) section whic was described by Stose and is generally taken as the reference section fo his usage. The lithic contrast between the proposed Shippensburg an Mercersburg Formations, however, is slight and they are apparently no practical mapping units at quadrangle scales in southern Pennsylvani (S. I. Root, personal communication).

The "Oranda" Formation is sometimes distinguished from the Mer cersburg by prominent dark shaly partings but is elsewhere very simila The formal definition of the unit is strictly paleontologic, however, an the name is taken from the type Oranda Formation of Virginia (Coope and Cooper, 1946) on the basis of presumed faunizone identity. Many au thorities do not accept this correlation (see Twenhofel, 1954) and quote are used with this term for Pennsylvania occurrences as indicative o doubts as to its legitimate applicability.

The Chambersburg Formation is more than 600 feet thick in the Chambersburg area (Stose, 1909; Craig, 1949) but thins northeasterly. It is not recognized on the west bank of the Susquehanna River (locality 1 of Appendix) where the maximum probable thickness is in the order of 200 feet, though structural as well as stratigraphic complications becloud the significance of this figure. The Chambersburg Formation is not definitely known in the Cumberland Valley sequence of Dauphin County. It is possible that rocks called upper St. Paul (?) in this report could represent part of the Chambersburg, assuming that metamorphic conditions could produce the substantial differences in apparent bedding characteristics. It does not seem reasonable that the termination at the Susquehanna River is absolute. It seems probable that slices of this formation are included in the Dauphin County substructure, but their position and thickness is speculative.

Martinsburg Formation

Shales and associated rocks predominantly composed of terrigenous clastics lying to the north of both limestone belts in Dauphin County are assigned to the Martinsburg Formation. These rocks form a terrane of great stratigraphic and structural complexity which has not been extensively examined in the course of the work reported here but has been the object of a separate study partially reported by Carswell and Hollowell (unpub. ms., U. S. Geol. Survey files). It is appropriate to summarize some aspects of the stratigraphic problems concerning these rocks, however, as they bear on the interpretation of the structure of the carbonate sequences.

The Martinsburg Formation of the main part of the Cumberland Valley is a typical normal flysch sequence providing clear stratigraphic evidence of an organic disturbance no great distance to the southeast. The rocks are predominantly dark-gray shales and siltstones, calcareous at the base and containing increasingly abundant, graywacke turbidite flows upward in the section. Sufficient faunal evidence shows these rocks range from Middle Trentonian (Sherman Fall) to Maysvillian in age. The thickness is not well established owing to repetitive lithology, indifferent exposure, and severe folding; but estimates in this area rarely depart much from the range of 2000 to 3000 feet.

To the northeast increasing metamorphism, the appearance of lithologies not represented in the type area, and the occurrence of some pre-Trentonian Deepkill-age graptolites has introduced considerably more variation in interpretations of the shale terrane. In the slate district between the Lehigh and Delaware Rivers the Martinsburg Formation is gradationally successional to the "cement rock" facies of the Jacksonburg Formation which has a fauna comparable to that of the lower Martins-

burg in the type area. The base of the Martinsburg is thus somewh younger in the Lehigh area, but the formation is certainly thicker by a amount that varies considerably with the structural interpretation of var ous authors. Allowing for the difference in metamorphic aspect, the litl ology in the slate district is quite similar to that in the Cumberland Valle but some workers have concluded that the stratigraphic sequence is di ferent. In the slate district there are two distinct belts of slate separated b a considerable thickness of sandy beds. The principal question is whethe these three belts represent stratigraphically successional units or whether th northern slate belt is a structural repetition of the southern belt. Both in terpretations have been supported by competent investigators who hav made detailed studies in the area, and it is apparent a positive criterio for resolving the question from internal evidence has not been disco ered. Willard (1943) made a general review of all the Ordovician clasti in Pennsylvania and concluded that a two-fold subdivision in the sla district with a lower shale and an upper sandy part similar to the situa tion in the Cumberland Valley, though with considerably more exte sive sandy development, was much more compatible with the region relationships. He concluded that the probable thickness of the Martin burg in the slate district is not greater than 4000 feet and likely closer t 3000 feet though greater thicknesses are indicated by some reports whic are by no means discredited.

Subsequent work has added little new stratigraphic information in th slate district to that summarized by Willard, though studies in progress b the U. S. Geological Survey (Drake and others, 1960) are giving consi erable insight on structural complexities. On the whole, the current opi ion is that Willard's interpretation of the slate belt stratigraphy is sub stantially correct. In this case, assuming depositional continuity, it is t be expected that along the strike of the Great Valley the true autochth nous Martinsburg Formation is a fairly uniform dark shale unit, calcareou at the base and sandy and silty in its upper part, which thickens som what in a northeasterly direction although becoming slightly younger a the base and possibly older at the top owing to pronounced developme of a pre-Silurian unconformity in the northeast.

Between the Cumberland Valley and the slate district a considerabl portion of the Great Valley shale belt is lithologically indistinguishabl from that to be expected from a simple extrapolation between these area but, in contrast with the uniformly gray argillaceous shales, siltstones, an sandstones of the typical Martinsburg, there are also abundant red an green shales, several varieties of limestones, siliceous argillites or bedde cherts, thick-bedded quartzites, conglomerates and some definite volcanic with pre-Trentonian graptolites associated with some of the anomalou lithologies.

Stose (1946, 1950) recognized that these rocks did not fit the normal rtinsburg sequence and proposed that a major part of the shale belt m the vicinity of the Susquehanna River nearly to the Lehigh River s part of a major Taconic thrust sheet which he designated the Ham- rg Klippe. While much of Stose's proposal has not been effectively uted in any substantial particulars, it has never been well integrated into general scheme of Appalachian structure; and most subsequent work- have treated it with great reservation. It would appear that Stose was ite correct in recognizing that the peculiarities of the Martinsburg in s area are part of the Taconic problem, and his Hamburg Klippe pothesis follows quite reasonably from the interpretation of the Taconic a proper in eastern New York and Vermont generally accepted at time he wrote. More recent work in the Taconic area (Bucher, 57; Craddock, 1957; Weaver, 1957), however, has shown that the previ- sly accepted supposition of a far-travelled overthrust of late Ordo- ian age is not a necessary, nor even the simplest, interpretation of the ologic relations, at least in the southern part of the Taconic Moun- ns. While the stratigraphic interpretations made by Bucher and his -workers cannot be applied to the Pennsylvania occurrences because nestones of the same age as the Deepkill graptolite fauna (uppermost nadian and Chazyan according to most recent workers) definitely do cur in immediate proximity to shales yielding occasional Deepkill grap- lites, the elimination of the classical style of Taconic thrusting at least the proximal part of the type area substantially undermines the analogy nich was an important element in Stose's argument.

The present study suggests that much, if not all, of the anomalous "aconic" lithology is associated with the Yellow Breeches thrust plate. ructural relations discussed in a subsequent section indicate that the esent disposition of the Yellow Breeches plate is the result of post- conic movement, and is thus not a Taconic thrust as inferred by Stose. ne probable existence of elements within the shale terrane as old or der than the younger carbonates of the Lebanon Valley sequence in- cates, however, that simple post-Taconic movement of the Yellow eeches thrust is not an adequate explanation for the stratigraphic pe- liarities of the shale in this area. Shale in shale conglomerates bearing agments of the "Taconic" lithologies occur in association with apparently tochthonous graywackes in the Harrisburg area and in all probability rrelate with sliding emplacement of larger blocks southeastward in the positional basin. Allowing for the subsequent displacement on the Yel- w Breeches thrust, it seems entirely reasonable to suppose that such ements of the shale terrane within the thrust sequence as may be of Her- ey or older age represent precisely such slide blocks. This emplacement ould not imply active local tectonism synchronous with deposition of the

shales of the allochthonous sequence, but it does indicate the proximi of Taconic orogeny to the southeast. Deformational structures of certa Taconic age in the Great Valley are thus not demonstrated by the pre ence of "Taconic" elements in the shale terrane, but the fact that tl inverted allochthonous sequence shows no indication of any strata young than (lower?) Martinsburg strongly suggests that the initial inversion w accomplished before the deposition of substantial overburden.

TRIASSIC SYSTEM

Gettysburg Formation

Red shales and sandstones with subordinate zones of quartz-pebb and limestone-pebble conglomerates of Triassic age underlie the hil bounding the south side of the Great Valley. These rocks have not bee examined in preparing this report, but are assigned to the Gettysbu Formation on the basis of numerous reports. The contact with the ca bonates is rarely exposed owing to colluvium from the Triassic hills, b the rare exposures as well as the geometry of the distribution suggest th the contact is everywhere steeply faulted.

Diabase

The Gettysburg Formation near the Lebanon Valley is abundantly i truded with diabase which is believed to have been emplaced in the sam epoch as extrusive basalts interstratified with Gettysburg Formation equiv lents in New Jersey, and hence to be of Triassic age also. The diaba is largely confined to the area of Gettysburg outcrop but a small dik swarm penetrating the Buffalo Springs Formation in the extreme soutl east part of the county is shown in a somewhat generalized form on th map of this report.

SURFICIAL DEPOSITS

No effort has been made to study or consistently map surficial deposi in the preparation of this report. They are generally shown on the a companying map only where they are of sufficient extent and thickne to materially reduce the confidence that may be attached to the bedroc mapping. They also generally indicate areas where exceptional thickne of overburden might be encountered in quarrying.

Where the deposits have been mapped they have been differentiate into two generations of Quaternary alluvium and artificial deposits; bu in no case was it attempted to show the full distribution or all the minc occurrences. The older alluvial stage is represented by gravel terrac well above the present streams and apparently is derived from Wisconsi outwash. These gravels are described by Stose (1928) and by W. C

ckock and F. T. Moyer (unpub. ms., Pa. Geol. Survey files). The nger alluvial stage is found in the modern flood plains of the larger eams. The artificial deposits are sanitary and structural land fill, quarry il, and slag.

STRUCTURE

The prominent structural feature of the carbonate rocks in Dauphin unty is their occurrences in two geographically isolated areas. The atigraphic differences between the rocks in the two exposure areas has en treated in the preceding sections, and it has been indicated that a jor thrust fault between the two areas is implied by these differ-ces.

The two stratigraphic sequences are also characterized by differences in tonic style; that is, the overall pattern of deformational structures they play. The rocks of the Cumberland Valley sequence are apparently tochthonous or at least parautochthonous, lying at or near their original e of deposition, and are overridden by the Lebanon Valley sequence cks of the same age. The character of deformation in the Cumberland lley sequence rocks, while perhaps somewhat more intense, is only a le different in style from that in the Ridge and Valley province to the rthwest. The structures within the Lebanon Valley sequence present an tirely different aspect. Here the strata are regionally overturned and en strongly sheared. Low-angle thrust faulting is frequently observed thin the sequence on various scales. The overturning and internal usting of the Lebanon Valley sequence appear to be the direct result emplacement of these rocks as a great thrusted overfold or nappe. Sev-al such nappes are commonly recognized in younger mountain systems ch as the Alps.

The concept of an Alpine-type nappe system in the Lebanon Valley veloping out of the current work, in part reported here, and the work Gray, Geyer, and others in Lebanon and Berks Counties (Gray, 1952a, 59; Gray and others, 1954, 1958; Geyer and others, 1958, 1963) can-t be entirely treated in a report of this scope; a general synthesis must ait further study. As the nappe system is presently conceived it in-ides all of the carbonate rocks of the Lebanon Valley sequence from wmansdale in Cumberland County to the vicinity of Reading in Berks unty, plus an indefinite portion of the Martinsburg Formation of the banon Valley, and all of the Martinsburg in the Steelton "syncline" lt. The rocks in the northern part of the Lancaster Valley south of the tervening Triassic basin are very similar to those in the Lebanon Valley quence, and may also be part of the same nappe system. The nappe stem thus extends about 60 miles along strike and is about 10 miles

wide in the Lebanon Valley in the vicinity of Lebanon where a maximu stratigraphic thickness of the allochthonous rocks is exposed. If the roc in the northern Lancaster Valley do, in fact, belong to the same syste the width is in excess of 30 miles, unless substantial stretching is suppos to occur transverse to the Triassic basin. The displacement of the alloc thonous rocks is not at all certain in view of the fact that the assignme of the closest and most remote possible dejection areas depends strongly assumptions made about unresolved problems of the Piedmont provin structures. On the basis of the facies difference between the Cumberla and Lebanon Valley sequences in Dauphin and eastern Cumberland Cou ties compared with impressions of the rate of facies change across t Massanutten syncline in the southern Cumberland Valley, it seems reaso able to suggest that movement in the Susquehanna River area was in t order of several tens of miles. Dimensions and transport of this magnitu are consistent with true Alpine structures.

The complete stratigraphic section of the nappe system is not prese in Dauphin County; but this area, with the adjacent part of Cumberla County, has proved a profitable area of study. In the Lebanon Vall proper, the shales at the base (stratigraphic top) of the allochthon ove ride very similar autochthonous shales which are very difficult to di tinguish and have been collectively called Martinsburg Formation, in pri usage commonly implying a normal stratigraphic sequence. At the wes ern end of exposure of the nappe system, however, the shales of the Le anon Valley sequence are exposed in contact with progressively old autochthonous formations and the character of the nappe can be mu more convincingly demonstrated.

YELLOW BREECHES THRUST

The thrust at the base of the allochthonous Lebanon Valley sequen has been named the Yellow Breeches thrust from five crossings of Ye low Breeches Creek in eastern Cumberland County. At its western end t thrust disappears against the Triassic border fault in the vicinity of Ros garden, about 3 miles north of Dillsburg on Highway U. S. 15. Fro this point for about 17 miles eastward it is defined by the lithic contra between shales of the thrust plate and various subjacent autochthono carbonate units. About 2 miles east of Rutherford, Dauphin County, e posures of the Cumberland Valley sequence carbonates and the thru trace are abruptly terminated, apparently by a tear fault. The probabl eastward continuation of the thrust surface lies entirely within a sha terrane and is much less certainly known. Manuscript maps of the Ma tinsburg Formation in Lebanon County by Mosely (Pa. Geol. Surve files) show a distinct textural break and a possible lithologic change ru ning approximately through the middle of the Martinsburg belt with mo

ordered structures to the south. This break is on strike with a thrust lt mapped in eastern Dauphin County by Carswell and Hollowell pub. ms., Pa. Geol. Survey files). A major break in stratigraphy and tonic style is also recognized in about the same position to the east Berks County (Meyers, personal communication). It seems quite prob- e that these features represent the sole of the nappe sequence in the le terrane, but the general similarity of the juxtaposed rocks and the ence of well-established stratigraphic markers in the Martinsburg kes the relationships difficult to demonstrate.

The extent of the Yellow Breeches thrust marked by a pronounced lithic ak and part of its probable extension into the shales of eastern Leb- on County are shown on the small generalized tectonic map inset of colored map accompanying this report (Plate 1). The overprinted a represents the carbonates of the Lebanon Valley sequence and that rtion of the Martinsburg Formation believed to overlie the Yellow eeches thrust, without implying that some other parts of the shale area t so indicated, notably in the Harrisburg area, may not also, in fact, long to the allochthonous system. The cross sections accompanying the tonic map are necessarily somewhat generalized and imaginative at pth, but surface control is based on the best available large scale map- g.

Examination of the geologic map (Plate 1) will show that details of Yellow Breeches thrust zone in Dauphin County are complex. As ny as three overlapping thrusts separating distinctive lithologies are own. Additional intraformational thrusts of uncertain magnitude and tent were observed in a number of exposures but are not practically ppable. Along the south side of the Harrisburg-Rutherford belt the llow Breeches thrust essentially superposes shales at the base of the ochthon on the St. Paul Group of the autochthonous Cumberland Val- sequence carbonates, but westward from the vicinity of Paxtang two ces of different lithology are caught in the thrust zone.

As indicated in the stratigraphic discussion, the lower slice is tentatively signed to the St. Paul Group. The tectonic position of this slice is one the principal factors leading to the previous suggestion that the litholo- peculiarities of these rocks may be the result of deposition in an en- ronment transitional between those characteristic of the Cumberland d Lebanon Valley sequences. It is clear that these rocks must have been posited somewhat to the southeast of their present position and hence ward the depositional site of the Lebanon Valley rocks. Two facts, how- er, suggest that only a small part of the total movement in the thrust ne occurred on the fault at the base of this slice. One is that, discounting e difference in lithic aspect produced by the deformational fabric im- essed on the thrust slice, the rocks much more closely resemble parts

of the autochthonous carbonate sequence than any probable unit in th allochthon. In addition the intensity and extent of deformation (tecto itization) of the uppermost part of the autochthon, presumably reflectir the amount of movement of the immediately overlying rocks, general appears to be substantially less where the Osp(?) slice is present tha where structurally higher elements are in direct contact with the autoc thon. It thus appears that this slice essentially represents a fragment c the subjacent Cumberland Valley sequence terrane dragged some unce tain distance by the overriding thrust sheet.

The origin of the upper slice caught in the thrust zone appears to b essentially similar, but the genetic affinity of the Hershey Formation ir cluded in this slice is clearly to the Lebanon Valley sequence. The roc of this slice, and that in the fault block on the north side of the west en of the Harrisburg-Rutherford belt which was presumably derived fro this slice, is not notably different from the Hershey in the Womelsdor Host reference area. The presence of the Hershey in this slice while pinches out east of this area along the main Lebanon Valley strike be was previously suggested to show that the axis of Hershey depositio trended more northerly than the present strike of the Lebanon Valle It seems probable, however, that the depositional locus of the Hershe near Harrisburg was substantially closer to that of the superjacent rock than the autochthon, and this slice, therefore, has been transported considerable distance. Poor exposure and the lack of definitive criteria fc distinguishing the relative amount of movement above and below the He shey slice largely preclude effective evaluation of this proposition on th basis of features in the outcrop. The local development of a greater vo ume of fault rock along the thrust between the Osp(?) and Hershey slice north of Steelton (Fig. 10) than has been elsewhere observed, however, a least suggests that the greatest movement was at this level, which is cor sistent with the stratigraphic inference.

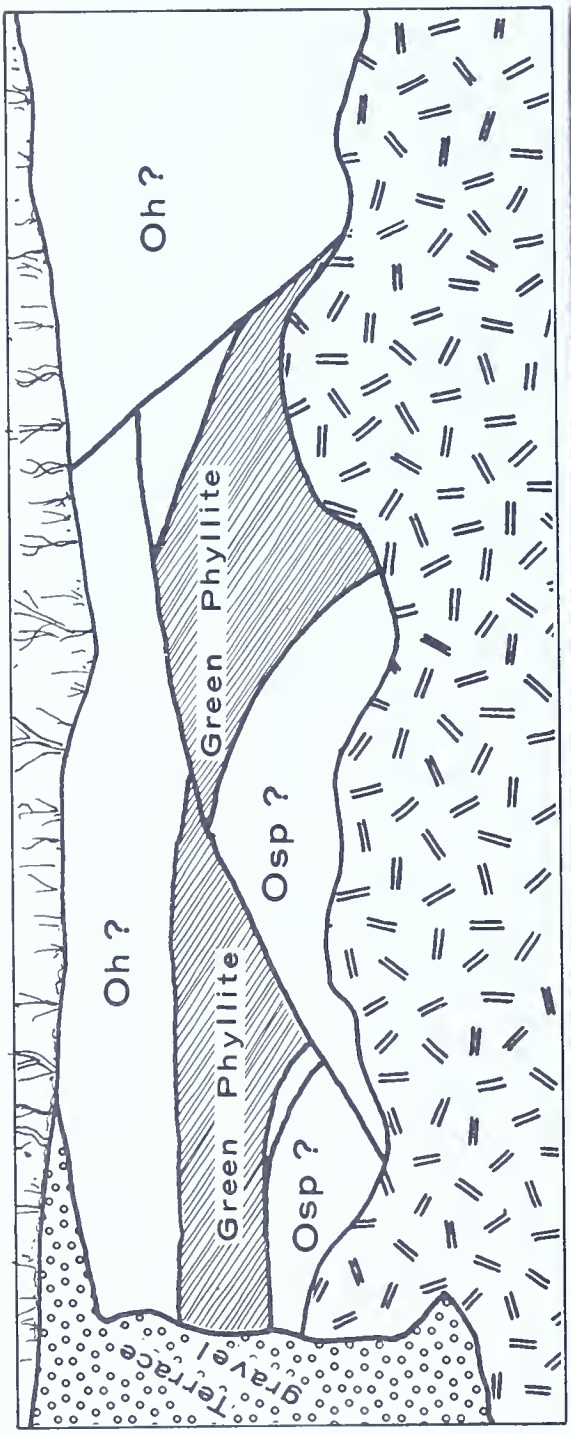
Owing to the higher topographic position of the shales of the thru plate relative to adjacent autochthonous carbonates as the result of di ferential erosion, the Yellow Breeches thrust is almost always conceale under some thickness of weathered shale colluvium. Its position may b mapped with an accuracy commensurate with that of most of the othe lithic contacts shown on the geologic map on the basis of topography an float, but actual exposures are rare. Figure 9 shows a temporary exposur of the main thrust in a sewer line excavation in the development lyin southwest of the Eisenhower Boulevard-Chamber Hill Road intersectio about 150 yards north-northwest of the Unitarian Church. Here mostl noncalcareous Martinsburg Formation overrides the limestone plate ques tionably referred to the St. Paul Group with no intervening Hershey lith ology. The pencil at the center of the photograph (about 6½ inches

gure 9. Yellow Breeches thrust, temporary exposure south of Paxtang. Dark-gray phyllitic Martinsburg shale thrust over heavy-bedded limestone of St. Paul Group (?).

ans a shaly gouge developed in irregularities of the limestone surface hich is not present in the lower left portion.

Figure 10 shows a portion of the thrust bringing Hershey lithology over e St. Paul Group (?), broken by later faulting. At this point, about 200 rds north of the Steelton Borough line just west of Cameron Street, veral feet of greenish phyllite occur in the thrust zone below the Her- ey. This phyllite is apparently absent at a smaller exposure a short stance to the north and is not apparently a general feature of this thrust. is supposed that the phyllite might have been derived essentially as an soluble residue from the Hershey lithology during dynamic metamor- ism along the thrust surface.

A third exposure in Dauphin County 2.8 miles east of the intersection ith Interstate Highway 83 on the south side of Highway U. S. 422 in a t behind a truck body shop shows the Martinsburg Formation directly erriding St. Paul Group without intervening slices. Details of the thrust e not readily apparent here, and the exposure is not illustrated. Shearing ithin the St. Paul Group near the thrust in this area, with development strong transport lineations on the bedding planes, gives the exposures aspect superficially more like Lebanon Valley sequence exposures than pical Cumberland Valley sequence rocks, but the lithologies are read-


Oh ?
Green Phyllite
Osp ?
Oh ?
Green Phyllite
Osp ?
Terrace
Gravel

related to less deformed St. Paul Group in the Harrisburg-Rutherford lt.

"Taconic" Thrust of Stose

In stratigraphic discussion of the Martinsburg Formation brief consid-ation was given to Stose's (1946, 1950) hypothesis that most of the artinsburg exposure in the Dauphin County area and eastward toward e Lehigh River was in fact part of a far-travelled shale thrust plate of 'aconic sequence" rocks. The essential reasons for this hypothesis are atigraphic; and, while it has never been effectively disproved, it was own that it is not a necessary hypothesis to account for the stratigraphic culiarities of the Martinsburg in this area. The present work has been ncerned with these shales only to the extent of attempting to establish eir relationship to the adjacent limestones and cannot provide a gen-al basis for evaluating Stose's ideas. Shale on shale thrusting of Taconic e could be present within the shale belt without affecting the observa-ns made here, as the oldest identified structures may be younger than conic; but the new data does call for re-evaluation of specific details of ose's interpretation.

In his 1950 "Comments on the Taconic sequence" Stose augmented his neral thesis (Stose, 1946) by consideration of the Steelton "syncline" ale belt in part covered by this report. He anticipated the conclusion of is report that the then-current interpretation of this structure as a rela-ely simple syncline was not consistent with the observable geologic re-ionships. He concluded that this shale belt should be included in his eviously defined Hamburg Klippe. The sketch map accompanying his per in many details is much more like the map of this report than the terpretation offered by the Geologic Map of Pennsylvania (Gray and epps and others, 1960) but differs in several important particulars.

The writer concurs with Stose in recognizing that all of the north side d at least a large part of the south side of the Steelton shale belt are ulted. Stose, however, concluded that these faults are continuous and present the leading and trailing edges of a relatively flat Taconic thrust derlying the shale and some associated "cement rock" exposures. The rust on the northern side is substantially identical to that here mapped the Yellow Breeches thrust; the relationship of the "cement rock" of ose (the St. Paul Group (?) and Hershey Formation rocks of the Har-burg-Rutherford belt of this report) has been previously considered. etailed examination of this thrust, briefly described above, leaves little ubt that Stose was essentially correct in delineating this feature; the fference lies in the inferred character and significance of the overlying rust sheet.

Stose's interpretation that faulting was continuous on the south side of

the Steelton shale belt and represented the trailing edge of a thrust shee was apparently forced on him by his understanding of the shale stratigraph and is not well supported by the field relations. Temporary exposures a Steelton (locality 3 of Appendix) positively confirm the existence of thrust at this point but show the shale overridden by and underlying th limestones rather than the contrary as supposed by Stose. Other ex posures of this thrust are lacking, but it probably extends at least to th eastern end of the narrow rectilinear part of the southern limestone belt The irregular contact between the Martinsburg and Myerstown Forma tions from this point northeastward to the vicinity of Fiddler's Elbow migh be depositional. This thrust is not, in any case, in the precise position c the "Taconic thrust" proposed by Stose, as he recognized a zone c "cement rock" (Myerstown Formation) above the thrust. There is ampl evidence, however, to show that the Myerstown is a normal part of th carbonate sequence in the southern belt. As the relations have been de veloped in this report the thrust at the south side of the Steelton shale be is simply one of a series of similar thrusts found within the Lebanon Val ley sequence which reflect the lateral transport of the whole mass. Thes thrusts all dip south or southeast approximately parallel to the sole thrus

Stose had long been aware of some stratigraphic differences betwee the carbonates on opposite sides of the Steelton shale belt (e.g. Stose an Jonas, 1927), though in the absence of the more recent detailed studie in the Cumberland and Lebanon Valleys he did not appreciate the di ferences in the Beekmantown Group and older strata. Prior to proposin the Taconic-thrusting hypothesis Stose had endeavored to explain the ob vious differences in the Middle Ordovician strata by stratigraphic pinch outs concealed under the supposed Steelton syncline. This interpretatio was perhaps admissible, allowing for the relatively small amount of th St. Paul Group that Stose (Stose and Ljungstedt, 1931) recognized i the Harrisburg-Rutherford belt as compared to the amount recognized b Prouty as shown on the 1960 Geologic Map of Pennsylvania (Gray an Shepps and others) and generally confirmed by this work, though har to reconcile with the map pattern of the western end of the Steelton bel even supposing the Beekmantown on opposite sides to be identical. Whe he discarded the Steelton "syncline" hypothesis in favor of the "Tacon thrust" hypothesis, however, Stose failed to reconsider the relationshi between the carbonates across the shale belt. If he had, he would almo certainly have concluded that the interpretation, which was already som what awkward with the synclinal hypothesis, becomes untenable; and h might, perhaps, more precisely have anticipated some of the major co clusions of this report.

It has previously been indicated in the remarks on the stratigraphy o the Martinsburg Formation that Stose's (1946) whole hypothesis of Tacon

e thrusting in this area rests largely on a supposed similarity to thrust-
g in the Taconic area of New York which was then generally accepted
t is now suspect. In terms of structural evidence within the present map
ea only the Yellow Breeches thrust has the general characteristics to
present possible Taconic thrusting. The relationship of the western ex-
sed end of this thrust to the nose of the South Mountain fold, however,
dicates that the thrust truncates, and is younger than, the folded struc-
re, which in turn appears to be younger than Taconic, indicating that
e present development of the Yellow Breeches thrust is almost cer-
inly not of Taconic age. Further consideration of this problem is more
propriate after the remaining structural elements have been discussed.

In conclusion, it would appear that the Yellow Breeches thrust, con-
dered part of a Taconic thrust by Stose, has certain similarities to that
hich would be expected from this designation but differs in several im-
rtant particulars. The concept of Taconic thrusting as generally under-
ood and as developed by Stose implies far-travelled thrusting of a pre-
lurian argillaceous block over carbonate-bearing rocks of comparable
e. The Lebanon Valley sequence includes carbonates in apparent strati-
aphic continuity with the shales above the Yellow Breeches thrust; and
e stratigraphic differences between the thrust slice and the autochthon are
least as apparent in the carbonate rocks as in the shales, implying a
splacement, while probably substantial, considerably less than indicated
the classic Taconic interpretation. The present development of the
ellow Breeches thrust also appears to be the result of events younger
an the Taconic age, though the influence of Taconic age deformation
defining the structure is not excluded.

STRUCTURES OF THE CUMBERLAND VALLEY SEQUENCE

In the main part of the Cumberland Valley the carbonate rocks are
rown into a number of asymmetric to somewhat overturned folds typi-
lly a mile or several miles from crest to crest. The structures are asym-
etric to the northwest and genetically related reverse faulting of the
eep limb is apparently not unusual, though younger faults of approxi-
ately the same attitude but less regularly related to the fold structure are
so present, as evidenced by the relatively frequent occurrence of younger
cks being thrust on older, for example, in the Carlisle quadrangle (Stose,
953). Subordinate folds associated with the major structures are present
t usually not mappable under the prevailing conditions of exposure in
e northern end of the Cumberland Valley. Microfolding is not charac-
ristic, and folds small enough to be encompassed in a single exposure
e not common. Owing to the relatively low erosional competence of
l the Cumberland Valley rocks the topographic expression of the Cum-
rland Valley folds differs substantially from that in the Valley and

Ridge province, but there does not seem to be any major difference i scale or style beyond that naturally attributable to lithologic differences

In the relatively narrow Harrisburg-Rutherford belt of Dauphin Count the entire exposure across the belt is apparently confined to the gentle southeast-dipping limb of one of the larger folds. This is most readil apparent in the general uniformity of dip in the long series of good ex posures on the west bank of the Susquehanna River opposite Harrisburg The photographs, Figures 11 and 12, show the west and east ends re spectively of the Hempt Brothers Quarry at Paxtang and illustrate th best exposed and largest known example of the subordinate folds of th Cumberland Valley sequence in Dauphin County. The rapid change i character along strike of these folds is apparent by comparison of the tw pictures which show cross sections of the structure only about 200 yard apart. The continuation of this fold has not been recognized at the Sus quehanna River about 1½ miles to the west. In view of the generall poor surface exposure, it is obvious that the axes of such folds cannot ordinarily be mapped. The steep northerly dips found on the south sid of this quarry, which become locally overturned steeply to the sout along the highway just to the south, are not common in exposures of th Cumberland Valley sequence in Dauphin County, but this occurrenc serves well to illustrate the general form of the larger structure of whic the Harrisburg-Rutherford belt constitutes only a single limb.

The jointing visible in these photographs can be seen to be approx mately perpendicular to the bedding in all parts of the structure, whic is characteristic of the jointing in most of the carbonates of this area Joints parallel to the regional strike are most conspicuous in these illus trations and are usually present. There are commonly additional join sets inclined to the strike set but the number and attitude of such se seems to be variable, and no mechanical analysis has been attempted. In cipient cleavage may occasionally be observed in this quarry and elsewhere in the Harrisburg-Rutherford belt but is never well developed. dips a little over 50° southward, approximately parallel to the cleavag in the Martinsburg Formation in the north.

The flat thrust fault apparent in Figure 12 in the core of the synclin at the east end of the quarry is not known to be a common feature in th Cumberland Valley rocks, but several other possibly comparable loc thrusts are exposed at places in the Harrisburg-Rutherford belt. It is n clear whether this feature is simply the result of squeezing out of the syn clinal core or whether it is the result of drag from the Yellow Breeche thrust which must have lain only a short distance above the present su face in this area. The fact that these local thrusts in the Harrisbur Rutherford belt are known only in rocks probably, at most, only a fe hundred feet below the projection of the Yellow Breeches thrust or th

sces in its sole suggest that the latter is perhaps the correct explanation. Apart from the plates in the sole of the Yellow Breeches thrust and e local thrusts just mentioned, faulting of any kind is quite minor with- the carbonate rocks of the Harrisburg-Rutherford belt. At the north ge of the belt, however, the carbonates are thrust upon the Martins- rg along a relatively steep fault with substantial displacement, as shown the fact that through much of the area upper Beekmantown Group cks lie against the Martinsburg Formation with all the Middle Ordo- ian carbonates missing. This fault was named the Paxtang thrust by louty (1959) and apparently represents an extension of the conjunction the Reading Banks thrust and an unnamed thrust of the Carlisle quad- ngle (Stose, 1953) (see tectonic map on Plate 1). It is thus part of the rust system associated with the northeast end of the South Mountain ticlinorium. The Paxtang thrust and others recently mapped (Carswell d Hollowell, Dyson, J. L., and Platt, L. B., unpub. maps and mss. in .. Geol. Survey files) represent an extension of the South Mountain fault stem through the Martinsburg Formation of Dauphin County, consid- ably farther to the northeast than is indicated on the Geologic Map of nnsylvania (Gray, Shepps, and others, 1960). While this group of faults known to cut only Ordovician and older rocks, this extension brings em into the neighborhood of the western known extent of the Sweet row fault. A genetic relationship between the South Mountain system d the Sweet Arrow fault has not been demonstrated, but now appears least theoretically and geometrically possible.

The Paxtang thrust is not actually exposed anywhere in Dauphin County. r the most part its trace lies under considerable shale colluvium and can only approximately specified. A dolomite outcrop a short distance north Derry St. on the Parkway in Paxtang lies within about 30 feet of shale at is probably *in situ*. This location provides the best near-exposure of e thrust in the county. Minor faults in the dolomite, possibly related to e Paxtang thrust, suggest that the fault here might be very steep, but e evidence is by no means conclusive. Exposure on the west bank of the squehanna River (locality 1 of Appendix) shows the thrust dipping a tle over 50° southerly, approximately parallel to the cleavage in the ales. On the basis of a limited number of observations elsewhere, this titude seems to be fairly characteristic of the faults in this system.

STRUCTURES OF THE LEBANON VALLEY SEQUENCE

Examination of the geologic map will show that the general dip of the banon Valley sequence carbonates is southeastward with progressively der formations exposed to the southeast. The inescapable conclusion is at the entire sequence is overturned. While many outcrops show no diag- stic criteria, a sufficient number show internal structural evidence of

Figure 11. West end Hempt Bros. quarry, Paxtang, showing folds in St. Paul Group. Local overturned beds just south of quarry. Total depth of quarry is about 175 feet.

Figure 12. East end Hempt Bros. quarry, Paxtang. Fold is apparently a little more open than in Fig. 11, but local thrusting is developing in synclinal core.

overturning to confirm this conclusion. Northwestward dips are much le common. While in some instances these dips almost certainly represe upright limbs of minor folds, in other cases it is clear that these are t result of overturning past recumbency.

It is to be expected that a great overfold producing this inverted s quence will have subordinate folds associated with it. These folds exist, but are frequently difficult to recognize. Most exposures of t Lebanon Valley sequence carbonates show fairly uniform southeaste dips without conspicuous folding. The laminated limestones, on clc examination, sometimes show quite complex deformation of the lamin even though folding of the major bedding planes is not apparent at t scale of the outcrop. Other small-scale folding is usually only conspicuc in the vicinity of thrust faults. Larger scale folding is reflected only one structure, the fold northeast of Hummelstown, which is of sufficie size to make its presence apparent in the map pattern of formational uni The effect of other folds of larger-than-outcrop size is apparent in t dip variations shown on the map, especially on the southeastern side; t these folds are relatively small with respect to the thickness of the cc taining formations and are not mappable under the existing exposu conditions.

The observable folds may be classed as three types: normal fol cross folds, and a few anomalous folds. The last class contains a f folds which bear no clear relationship to the major structural elemen They are tentatively attributed to a late subordinate phase or phases deformation and will not be considered further here.

The normal folds are abundant and exist at all scales. They have a approximately parallel to the regional strike and usually have fairly l plunge. Axial surfaces, where defined by cleavage or bed geometry, co monly dip southeasterly at a low to moderate angle, but are sometin fully recumbent and occasionally slightly tilted northwestward. Some these folds are apparently normal responses to the regional transpc others are more properly drag folds associated with the thrusting, t both are products of the same general stress configuration and have t same orientation. Theoretical consideration of general Appalachian str ture and stratigraphy lead to the inference that the rocks of this area w subject to more than one stage of deformation. Some confirmation of t inference may be deduced from indications of warped cleavage and oc sional development of a second cleavage; but, insofar as has been det mined, all substantial deformation is homoaxial, and the effects of proba successive deformations cannot be separated.

The cross-fold axes are parallel to tectonic transport as shown smear lineations in bedding and cleavage. The plunge of the axes is qu variable depending on the general orientation of the beds on which

ılds are developed but the direction is quite uniform to the southeast. ıese folds are symmetrical and only rarely tight. Most known examples ınge from a few inches to a few feet crest to crest, but the large-scale, own-dip undulations observable in some of the Annville Limestone uarries are a much larger scale example of the same phenomenon, which ould probably be recognized elsewhere in the area if the exposure were mparable. These cross folds are considered syngenetic in that their close ılation to the transport lineation shows that they developed during the ıase of substantial movement which was almost certainly the time of ıajor thrusting and substantial folding of the normal type. As previously idicated, however, not all the normal type folding is certainly the result a single event, whereas it seems probable that the cross folding is.

The photograph, Figure 13, shows examples of the small-scale struc-

ıure 13. Prominent flat cleavage development in Buffalo Springs Formation, in nearly vertical beds with laminae showing recumbent convolutions.

tures associated with folding in conspicuously deformed rocks of e
Buffalo Springs Formation. General bedding in this meso-fold crest s
nearly vertical, with small-scale recumbent folds shown by contor
laminae. The axial plane cleavage is nearly horizontal and is here ma
conspicuous by differential weathering. An incipient second cleava
steeply inclined to the left is less conspicuous but may be detected
careful inspection of the photograph. On the limbs of such folds,
areas where bedding contrasts are slight, laminae are often smeared
along the cleavage to produce a compositional banding of tectonic ori
(false bedding) with true bedding difficult or at times even impossible
ascertain.

The conspicuous structural feature of these rocks, however, is not t
folding but the evidence of substantial lateral transport. This is distribut
through the rock body as shown by fairly wide-spread development
transport or smear lineations developed on bedding and cleavage su
faces, (Figure 14) and is concentrated along discrete thrust surfaces. T
latter include not only the relatively large interformational thrusts sho
on the geologic map but also numerous smaller intraformational thru
which usually can be recognized only in single exposures and are not ma
pable. Actual exposures of the larger thrusts are not generally abunda
though their approximate position can often be recognized by increas
deformation of the adjacent strata as well as stratigraphic anomali
Figure 15 shows some details of one of the better exposures, the thr
contact between the Annville and Myerstown Formation on the east ba

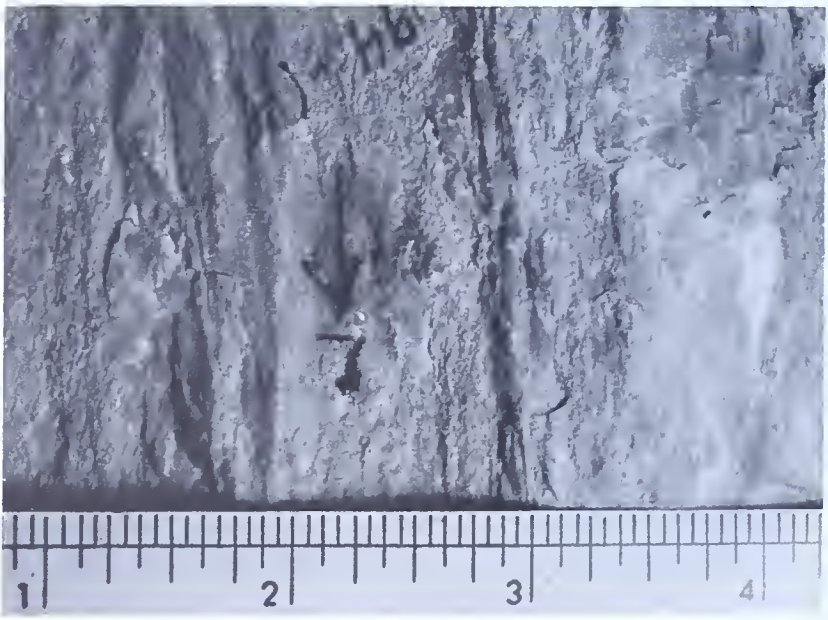


Figure 14. Transport lineations on bedding surface of the Epler Formation.

Fure 15. Detail of thrust contact between Annville and Myerstown Formations on Swatara Creek just south of Route 422. Platy lithology here is younger than basal Myerstown Formation.

Swatara Creek near U.S. Route 422 highway bridge. The fold in the aty Myerstown beds is a crossfold parallel to the grooving on the fault rface. This thrust is a continuation of the thrust in the section at Fid-r's Elbow (locality 5 of Appendix). Only a small thickness of the yerstown is apparently present here, presumably in thrust contact with e Martinsburg Formation though actual relations are concealed by atara Creek.

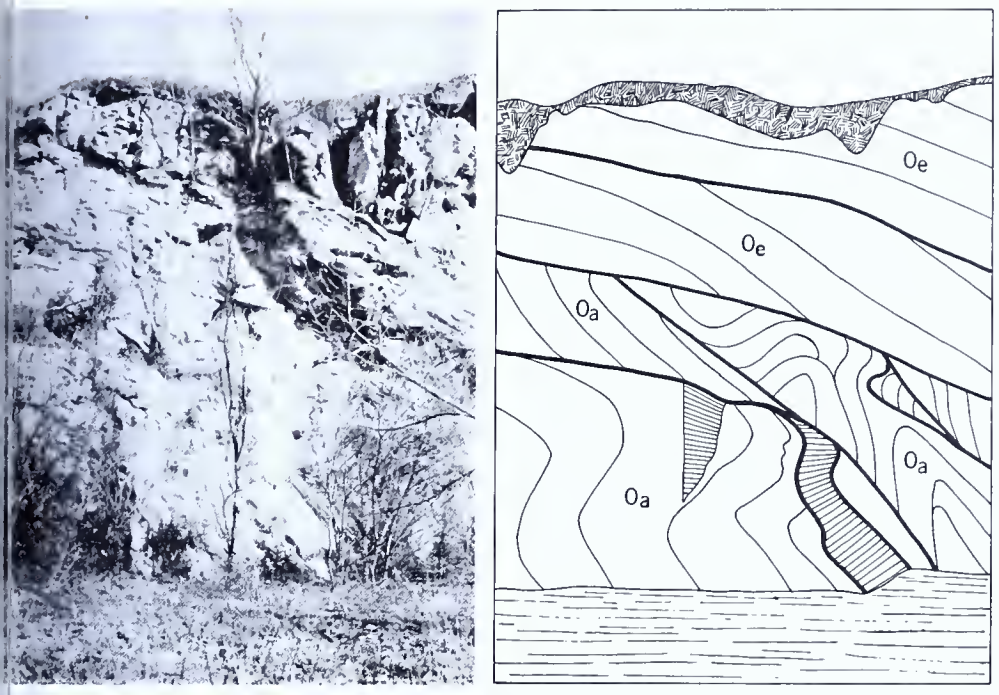
The largest thrust within the carbonate sequence is the South Lebanon ust which may be traced with some confidence from the vicinity of lbach, Lebanon County, only a few miles west of the Berks County

line, to its intersection with the Triassic border southeast of Hummel town. At its western end, all of the Conococheague Group plus an i definite portion of the Stonehenge and Buffalo Springs Formations a missing. The intersection of the nearly horizontal thrust surface with t strata which show a rather gentle southeasterly mean dip is such that t geometry indicates a minimum of several miles displacement. The d formation and shearing of the strata within several hundred feet of th thrust is the most intense observed anywhere within the Lebanon Vall carbonates. The displacement on this thrust is considered to be much le than that on the Yellow Breeches thrust, but the movement of the latt was in the less competent shales and effects of the movement are not pa ticularly conspicuous in the closest carbonate units. The intensity deformation, especially as reflected by cleavage development, may seen by comparing the Stonehenge Formation exposure of Figure 3 a the Buffalo Springs Formation exposure of Figure 13, both of which a from stations in the neighborhood of the South Lebanon thrust, wi more typical exposures away from a major thrust zone such as is shov at the Epler-Ontelaunee contact in Figure 4.

The thrust between the Epler and Annville Formations south of Ste ton is on strike with, and may well represent an extension of, the Sou Lebanon thrust though it was not possible to demonstrate continuit Both of these thrusts are generally very poorly exposed, but the latter h an excellent exposure at the east end of the abandoned cut on the nor side of the Bethlehem Steel Company quarry at Steelton, illustrated Figure 16. This cut shows on a large scale several features common observed in the thrusts of the Lebanon Valley sequence. The main thru surface, across which the Ontelaunee Formation and parts of the Epl and Annville Formations are missing, is the central part of the figu Subordinate thrusts within both Epler and Annville are found on eith side of the main thrust. Such multiple slices are apparently common, a in many cases the map symbol for a thrust represents a system of th type. It may be observed that the bedding in the uppermost plate is su stantially parallel to the thrust surface. The underlying rocks are mo deformed. This structural style is common to most thrust exposures the area. These thrusts commonly have an attitude very close to the me regional dip and almost rigorously parallel to the bedding of the upp plate.

PROBABLE AGES OF STRUCTURAL ELEMENTS

While original work in the Appalachians attributed the deformati of this system to a single major "Appalachian Revolution" of La Paleozoic age, subsequent work, particularly in the more complex sout eastern part, has shown that Upper Ordovician (Taconic) and Upp



ure 16. Multiple thrust contact of Epler and Annville Formations, north wall of Bethlehem Steel Co. quarry, Steelton. Bedding of upper plate parallel to thrusting and disturbance of beds below thrust is characteristic of thrusts in the Lebanon Valley sequence.

evonian (Acadian) deformation is at least equally fundamental in the erall development of the orogenic system. While the Allegheny Revolution of Woodward (1957) is temporally identical with the older "Appalaian Revolution," it was proposed to distinguish that part of Appalachian formation, not necessarily the most profound, which occurred near e end of the Paleozoic in distinction to the older concept, and the term so employed here.

Within the area of detailed mapping covered by this report there is ly limited inferential evidence for assigning geologic ages to any of the served structures and even the evidence for relative ages of the structral elements is incomplete. Taken in context of the surrounding areas d the regional setting, however, some reasonable propositions and limits ay be established.

In the Valley and Ridge province northwest of the Great Valley there abundant stratigraphic evidence of Taconic and Acadian orogeny to e southeast in the form of thick synorogenic and post-orogenic clastic dges, but structural evidence of these events is limited at best to cal development of slight to moderate angular unconformities. In this ea, from which the classic Appalachian Revolution was described, it ems quite true that most or all of the substantial deformation is of ate Paleozoic (Allegheny) age.

Southeast of the Great Valley in the Piedmont, normal stratigrapl paleontologic criteria are not available for establishing the age of c formation, but the ages of metamorphic events which bear a logi relation to orogenesis may be established by radiometric methods. Su determinations, of which the study by Lapham and Basset (1964) is recent example, show metamorphic ages of about 330 million yea (Acadian) and 460 million years (Taconic) with little evidence of a d tinct late Paleozoic stage in the Pennsylvania Piedmont or nearby are Theoretical considerations and limited empirical data suggest that t locus of deformation moved northwestward with decreasing intensity du ing successive orogenic stages. Thus the terminal Allegheny stage w the most important in the marginal sediments now composing t Valley and Ridge province, but it was not sufficiently severe to produ significant igneous activity or metamorphism in this area and left litt impress on the Piedmont rocks which were previously affected by mo profound events.

Implicit in the foregoing discussion is the well known difference in tl style of deformation in these two very dissimilar areas as well as tl difference in age of deformation. The Great Valley constitutes actually relatively narrow transition zone between the Ridge and Valley and tl Piedmont, and it is reasonable to expect it will show significant influen of the factors affecting both of these provinces. This expectation is just fied at least in the sense that it has structural elements with style sugge tive of aspects of both Piedmont and Valley and Ridge deformation While the internal evidence is not entirely conclusive, it seems reasonab to suggest that at least the elements most resembling Piedmont deform tion in style are of pre-Allegheny age.

It is a usual experience in an area of repeated deformation that th oldest deformation is the most difficult to identify, but discrete eviden of the Taconic Orogeny in the carbonates of Dauphin County is pa ticularly elusive. It was previously noted in discussion of the Martinsbu Formation that large synorogenic allochthonous blocks apparently sli in the area in which the "Hamburg Klippe"-type Martinsburg was de posited. This implies close proximity to a tectonic uplift which migh well have affected the underlying carbonates. There are no structure within the carbonates which can be clearly assigned to this cause, bu there is one peculiar structural-stratigraphic fact which suggests th Taconic Orogeny had profound influence on the rocks of the Lebano Valley sequence. This fact is, that despite the Acadian or later move ment of the Yellow Breeches thrust, stratigraphically the overturning o the Lebanon Valley sequence is almost certainly a feature of Taconi origin. This extensive regionally inverted sequence, so far as is known everywhere has (lower?) Martinsburg Formation in its sole overlain b

progressively older rocks. The mechanics of forming the immense overturned block are difficult to visualize at best; but the problem of performing this feat under a considerable cover of younger sediments, as would be necessary if this were an Acadian or younger event, and then sliding it off neatly with none of the younger sediments infolded is almost insuperable. It is clearly more probable that the overturning took place prior to the deposition of any substantial overburden while the sediments may have been in part poorly lithified. In view of the fact that active Taconic folding of the Great Valley carbonates has been recognized in the Lehigh Valley to the northeast (Drake, 1960) and that probably only slightly more active tectonism than is reflected in the Martinsburg flysch of the Harrisburg area would be necessary to generate a substantial peel thrust in the carbonate substrate, there is a high logical probability that the essential development of the Lebanon Valley inversion is a Taconic event. There is, however, little solid evidence. There is no evidence of Taconic deformation in the Cumberland Valley sequence rocks and the Martinsburg Formation of this area does not suggest the same close approach to a locus of tectonic activity as does the Martinsburg associated with the Lebanon Valley carbonates.

Acadian deformation is probably represented by a substantial portion of the folding in the Cumberland Valley sequence and possibly by the emplacement of the Yellow Breeches thrust and the presumably synchronous movements within the thrust sheet. Within the area of the tectonic sketch map of this report (Plate 1) the positive evidence for the relative antiquity of much of the Cumberland Valley folding is the relationship between the folds on the plunging nose of South Mountain and the Yellow Breeches thrust. As these folds are truncated by the substantially undeformed thrust surface it is probable that not only folding but substantial erosion preceded the thrusting. As the Yellow Breeches thrust itself may be late Acadian and is certainly cut by later Paleozoic faulting, the internal structural evidence suggests that this folding is not younger than Acadian while the stratigraphy of the Cumberland Valley strongly suggests that local deformation is entirely post-Taconic. Acadian deformation in the South Mountain area is independently concluded by V. Gwinn (personal communication) on the basis of broad tectonic synthesis and is an almost necessary logical inference from the Acadian radiometric age recently reported by Pierce and Armstrong (1966) from a thrust mylonite in the proximal part of the Valley and Ridge facing South Mountain.

The suggested Acadian age of the Yellow Breeches thrusting is much more speculative and rests largely on the argument of comparative tectonic styles, and the fact that it is demonstrably older than the steep thrusts which seem most related to the character of Alleghenian deformation in

the Valley and Ridge province. Full development of the argument of comparative tectonic styles would require a fairly extensive review of structural features in eastern and central Pennsylvania and is beyond the scope of this report. It may be summarized, however, by the observation that the mode of deformation in the Lebanon Valley sequence is quite unlike Alleghenian deformation as exemplified by structures of the Valley and Ridge province but is quite similar to that in the northern Lancaster Valley of the Piedmont where the deformation is thought to be primarily pre-Alleghenian and largely Acadian (Wise, personal communication). It must be recognized as possible that the similarity in style between the Lebanon Valley and the Piedmont may result from different tectonic stages in which essentially similar conditions of deformation were repeated with a shifted axis, but this coincidence seems particularly unlikely in what is known of the tectonic evolution of this part of the Appalachian system.

The thrusting and folding within the Lebanon Valley carbonates, with minor exceptions possibly attributable to subsequent deformation, have a style and geometry entirely consistent with the conclusion that they were formed at the same time as the emplacement of the Yellow Breeches thrust. If the inference that the initial inversion of these rocks is a Taconic event is correct, it is logically probable that some part of the internal structure is older than the Yellow Breeches thrusting; but, if such older structures are present they cannot be distinguished. Assuming such Taconic structures were developed they might not be apparent either because they were substantially obliterated during subsequent deformation or the two epochs of deformation developed homoaxial stress fields resulting in structures which are geometrically indistinguishable.

Alleghenian deformation may have produced some warping of thrusts and cleavage in the Lebanon Valley and possibly intensified folding in the Cumberland Valley, but relatively steep reverse faults irregularly related to pre-existing folds seem to be the conspicuous feature probably attributable to this phase. The Paxtang thrust is the sole example of this type within the detail map area, but faults of this type are extensively developed to the north and west. These thrusts suggest a movement picture quite consistent with deformation in the Valley and Ridge province. The Paxtang thrust and inferentially several related thrusts lying entirely within the shale terrane to the north are offset by tear faults which are thus still younger, but probably also of Alleghenian age. The tear west of Hummelstown is geometrically similar and may be of the same age, but there is no direct evidence of its age relative to the steep thrusts and thus it might also be a feature of the Yellow Breeches movement.

The Alleghenian faults seem to be the youngest expression of compressional or translational deformation. Normal faulting is considerably more abundant than is suggested by the geological map because faults

re commonly shown only where they define or visibly offset lithic contacts t the mapping scale. Many of these are demonstrably Triassic or younger y virtue of their relation to the Triassic sediments at the south edge of he mapped area but it cannot be positively asserted that some normal aults within the carbonate terrane are not substantially older. The grain f the Paleozoic structures has had a strong influence on the orientation f clearly Triassic (or later) faults in this area. A geometric distinction etween Triassic and possible older normal faults is not anticipated.

CHEMICAL COMPOSITION

The chemical composition of the carbonate rocks is of some use in lemonstrating stratigraphic correlation and transition and is the paranount factor in determining suitability for use in the more critical applications. The available chemical data about Dauphin County rocks is ather meager, but with the addition of data from adjacent counties at east a fair approximation of the composition in the county may be obained.

Five new analyses of the Annville Limestone were made for this report. The remaining analyses are obtained from files and publications of he Pennsylvania Geological Survey. The analyses are of two kinds: those vhich give the composition of a particular bed, and those which reflect the nean composition of a number of beds. The latter may consist simply f the total analysis of a drill hole core or cuttings, or the product of a quarry; or they may be obtained by averaging a number of individual nalyses. In this case the analysis may be more or less representative of he entire unit sampled depending on whether or not the total is adjusted o the relative abundance of each material sampled. For each formation n effort has been made to assemble analyses which reflect both the lithic ariability of the unit and its overall composition. In some cases only nweighted averages are available to suggest bulk composition, however. n comparing the graphs of analyses it is desirable to remember that the riginal data is variable in source, reliability, and intention; and that, in ome cases, it was necessary to include samples taken a considerable disance from Dauphin County to get a sufficient number of analyses.

GRAPHICAL SYSTEM OF PRESENTING ANALYSES

The individual analyses of most of the units have not been tabulated in his report. Complete analyses are given for the Annville Limestone and he Ontelaunee Formation, which are of particular interest owing to their economic potential, but data for all units is presented graphically on triangular diagrams.

The graphical system of presentation does not show the relative proportions of the minor constituents but it is a very effective method of summarizing the major components in a manner which facilitates synthesis of the variability and mean composition, and comparison of different units. The triangular diagram also provides a convenient objective system for assigning lithologic names on the basis of chemical analysis.

Relation of Rock Types to the Triangular Diagrams

The large triangle in Figure 17 shows the full-sized diagram used in this report with the fields occupied by the various types of carbonate rocks indicated on it. These fields differ from those used by Gray (1951) in that his Magnesian-Limestone field has been subdivided into a Magnesian and a Highly Magnesian field. This division is made to approximate the field distinction between "limestone" and "dolomite" made on the basis of appearance and reactivity to weak acid. Many of the "dolomites" of field

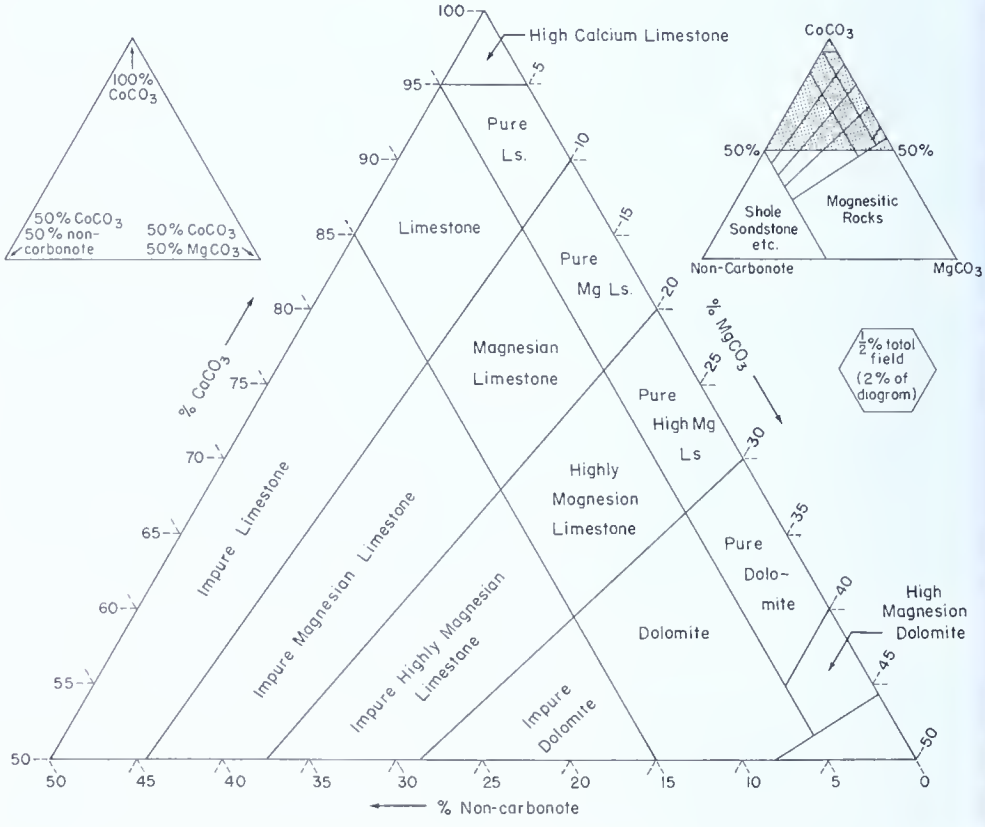


Figure 17. Triangular diagram of carbonate rock composition used in this report showing the fields of various rock types. See text for full discussion.

nomenclature are analytically highly magnesian limestones. It is noteworthy that, in the following triangular diagrams of analyses, the vicinity of the division between the Magnesian and Highly Magnesian fields corresponds to a real paucity of reported analyses for individual rocks. A number of composite analyses, of course, fall in this region, but these are not relevant to actual lithologies. While rocks of intermediate composition could be common elsewhere, in this area at least, there seem to be two distinct rock groups, one grading from pure calcitic to magnesian, the other grading from dolomitic to highly magnesian with intermediate material only sparingly represented. The fields of Figure 17 have also been modified from Gray's (1950) usage in that he distinguished only between pure rocks with less than 5 percent noncarbonate and impure rocks with more than 5 percent. In order to avoid encumbering the nomenclature by constant repetition of pure and impure, the common rocks, neither notably pure nor impure, with 5 to 15 percent noncarbonate content are simply designated without the modifiers. The highly magnesian dolomite field has also been changed from the geometrically defined field of Gray (1950) to a field ($MgCO_3$ greater than 40 percent, noncarbonate less than 5 percent) that is comparable to the definition of high-calcium limestone.

Preparation of the Triangular Diagrams

The diagrams are prepared by the method of Gault (1950) as employed by Gray (1951) with a few modifications. The basic diagram is so constructed that the apex of the triangle represents 100 percent $CaCO_3$, the lower right corner 100 percent $MgCO_3$ and the lower left corner 100 percent noncarbonate (insoluble) constituents, i.e. Al_2O_3, Fe_2O_3, SiO_2 and any other minor components in the analysis. Any carbonate rock analysis which totals 100 percent can be represented on the diagram as a single point, the proximity of which to each corner represents the percentage of the constituent. The basic diagram is shown as the small triangle in the upper right of Figure 17 but as all the analyses reported contain 50 percent or more of $CaCO_3$, the data are actually presented on diagrams covering only the shaded portion of the basic diagram. The lower left and lower right corners of the triangle then become 50 percent $CaCO_3$-50 percent noncarbonate and 50 percent $CaCO_3$-50 percent $MgCO_3$ respectively as shown in the small triangle at the upper left of Figure 17.

The initial step in preparing Figures 20-24 consisted of plotting the available analyses of each formation as points on the appropriate diagram. The result is a scatter diagram showing the distribution of observed analyses. Where the number of observations is small such a scatter diagram best summarizes the available data. But it should be noted that the extreme values recorded may have a very low occurrence frequency when a larger body of data is analyzed, and thus are unrepresentative of the

unit as a whole. Where a sufficient number of analyses is available, the grouping and distribution of the points has been emphasized by a statistical analyses, like that used by Gray (1950), performed in the following manner. A hexagon, having an area equal to 0.5 percent of the triangular field $CaCO_3$-$MgCO_3$- noncarbonate (2 percent of the partial field $CaCO_3$ greater than 50 percent used in Figures 20-24 as shown in Figure 17), was moved in steps across the diagram. The number of points falling within the hexagon was recorded at its center at each predetermined interval. The entire area of the triangle was covered in this manner. Each number thus obtained was converted to a percentage of the total number of analyses plotted in that diagram, and lines were drawn connecting points at equal percentage. The significance of this procedure is best illustrated by an example. In Figure 23B the area between the 4 and 8 percent contours is represented by dark stipple shading. If the center of the hexagon is placed anywhere in this shaded area, between 4 and 8 percent of all observed analyses plotted on this diagram will fall within the hexagon. By this method the background "noise" of low frequency extreme analyses is eliminated; and the overall composition and the trend of the variability of the unit sampled is more clearly shown.

Significance of Diagram Contours

It is obvious that the reliability attributable to a given percentage contour as a reflection of the actual composition of the whole formation will depend primarily on the number of samples and secondarily on the observed dispersion of data. Precise statistical methods for estimating the confidence limits to be attached to such observations based on these parameters perhaps might be derived, but the computation would be tedious and the results meaningful only to a statistician. The complexity of the problem may be understood by considering that the contours may be taken to represent elevation contours on a three dimensional, in most cases obviously not Gaussian, frequency distribution surface of the observed sums of three variables.

A less formal approach, however, permits at least evaluation of the lowest contour value that is probably indicative of the composition of the whole unit. It is apparent that any given analysis may be fairly representative of the type of rock occurring in a particular formation; or it may represent "noise" in the sense that the analysis may be defective or the particular rock type sampled may be a volumetrically insignificant part of the entire unit. In contouring the diagram it is desirable to set the lowest contour so that the effect of "noisy" analyses is averaged out. The percentage value of this contour will be dependent on the number of analyses from which the percentage is derived. In Figure 21B, for example, there are 51 analyses reported. Each analysis therefore generate

a 2 percent contour, and the random near coincidence of two noisy analyses could generate a spurious 4 percent contour. A 2 percent contour on this diagram is obviously meaningless and the 4 percent contour should be regarded with reservations concerning the accuracy of its approximation to the configuration that would be obtained from a much larger number of analyses. On a purely statistical basis the probability that a random sample of 51 determinations drawn from an infinite population would contain two determinations which are both nonrepresentative and nearly coincident is almost vanishingly small; but it should be born in mind that the sampling for the analyses actually reported is biased by the objectives for which it was performed and is definitely not strictly random. In Figure 23B, 231 analyses are reported. As analyses are given for two points in all but one bed sampled, there is a strong bias toward pairing of observations. Thus the near coincidence of as many as four analyses could be essentially "noisy" at a low level of probability, but the 2 percent contour represents the occurrence of nearly five analyses in the area of the hexagonal counter. Thus the 2 percent contour of Figure 23B is a more reliable approximation of the configuration of all possible analyses than is the 4 percent contour of Figure 21B.

The contouring in Figure 23B has precisely followed the computed percentages on the counting grid. It will be observed that the contours are relatively smooth as might be expected where small chance variations in the position of a single analysis will have small effect on the position of the contour. In diagrams based on fewer points the effect of small chance variations of a single determination will have considerable effect on the smoothness of the contours. The minor irregularities thus produced have no real relationship to the overall composition of the unit sampled and have been smoothed out to some extent in the published diagrams to facilitate comparisons.

INSOLUBLE RESIDUES

One hundred and thirty-three insoluble residue determinations were made during the course of this investigation. This phase of the project was undertaken largely to assist in the resolution of stratigraphic problems, and does not represent a systematic sampling of all the rocks in the area. The results of these determinations, however, do shed some additional light on the composition of rocks in this area. The insoluble residue is essentially the same thing as the noncarbonate component of the triangular diagram though there may be minor differences owing to the difference in method of determination. It is possible, therefore, to compare the insoluble residue determinations with the chemical analyses and draw inferences as to whether the reported analyses are representative of the rocks on which insoluble residues were determined.

The insoluble residue gives no indication of the calcium-magnesium ratio of the rocks, but if the distribution of the third component is comparable by the two techniques it is reasonable to assume that the analytically determined Ca-Mg values are also comparable in the other rocks. This is particularly helpful in evaluating the applicability of the analyses obtained outside the county to the rocks within the county. While there is no assurance that the Ca-Mg ratio does not change away from county except such control as is provided from analyses within the county; the agreement between the insoluble residues of the Dauphin County rocks and the noncarbonate of the analyses increases the confidence in the applicability of the analyses.

As all insoluble residue determinations were made on single rock specimens rarely representing more than 4 inches stratigraphically whereas the chemical analyses almost invariably represent a substantially greater thickness, it is to be expected that the insoluble residue determinations will show a somewhat greater variability even on a random basis. As the determinations were in fact made for stratigraphic reasons to include obviously extreme samples and samples whose stratigraphic position was doubtful because their lithology was atypical, the range may be expected to be larger than would be predicted on a random sampling basis. For these reasons a somewhat larger spread of insoluble residue determinations than analytic noncarbonate determination should not be taken to suggest that the rock composition is more variable than indicated by the range of chemical analyses. If the insoluble residue range is symmetric with the analytic range and the majority of both determinations have about the same values it is reasonable to suppose that the greater range only represents the difference in sampling technique.

Presentation of Insoluble Residue Data

The insoluble residue data has been presented on the same triangular diagrams as the chemical analyses. As the insoluble residue of a rock is essentially the same thing as a noncarbonate determination, but the $CaCO_3$-$MgCO_3$ value is indeterminate, an insoluble residue may be represented on the diagram as a line parallel to the $CaCO_3$-$MgCO_3$ join at distance determined by the percent insoluble residue. In order to show the relationship between the observed residues and the chemical analyses five such lines have been drawn where there is sufficient data to define them. The outermost two lines (labeled R on diagrams) represent the highest and lowest observed values and the distance between them, the observed range. The central line ($\overline{X}$) is the mean value of all observations. The two intermediate lines (D_1 and D_9) represent approximately the 10th and 90th percentiles respectively of observations as determined to the nearest whole observation. These lines give the range of 80 percent of

ıe observations with the most extreme 10 percent removed at either end.)wing to the tendency for a wider range of insoluble residue determina- ons than analytic noncarbonate discussed in the preceding paragraph, ıe D_1-D_9 range is often a closer approximation of the observed non- ırbonate range than is the total range of insolubles. The fit of the in-)luble residue statistics R, D_1, D_9, and $\overline{X}$ to the analytic data will be)nsidered with the evaluation of composition of the individual forma- ons.

DISTRIBUTION OF NONCARBONATES AND IRON WITH RESPECT TO DOLOMITE

The chemical analyses examined in the process of preparing this re- ort make it possible to evaluate two generalizations that have been made)out the carbonate rocks in this area. The most frequently repeated gen- alization is that, with the exception of the shaly limestones at the top the sequence, the dolomitic rocks are less pure (higher in noncar-)nate constituents) than the associated limestones. This statement has casionally been extended to support the inference that the same depo- tional conditions are condusive to deposition of noncarbonate sediments ıd $MgCO_3$. In this case a linear relationship between the two is indi- ıted. The second generalization is that the yellowish weathering color,)und on virtually all dolomitic rocks in this area is the result of iron the dolomite. The analytic results support the latter statement, but ıe first must be highly qualified to be meaningful.

Noncarbonate vs. Dolomite

The triangular diagrams may be considered as including a distorted aph of the noncarbonate content as a function of the $MgCO_3$ content. o be viewed in this manner the $MgCO_3$-$CaCO_3$ join is to be considered ıe x-axis with $MgCO_3$ increasing from right to left. The y-axis is then ırallel to the $CaCO_3$-noncarbonate join and the noncarbonate values are ad parallel to this join rather than perpendicular to the x-axis. The trend ıe of compositional variation is then a statistical plot of the desired nction.

The same function derived in a different manner is shown in Figure 18. hese curves were prepared by ranking all observations for each variable rmation in order of $MgCO_3$ content. The scatter of observations was duced to a smoothed curve by running averages in both x and y. The sults of this method differ slightly from the trend obtained by contour- g for two reasons. First, the running average gives maximum weight extreme values while contouring minimizes their effect. Second, the ntouring is controlled by an area on the graph of fixed size and shape hile the graph area represented by each successive average is variable

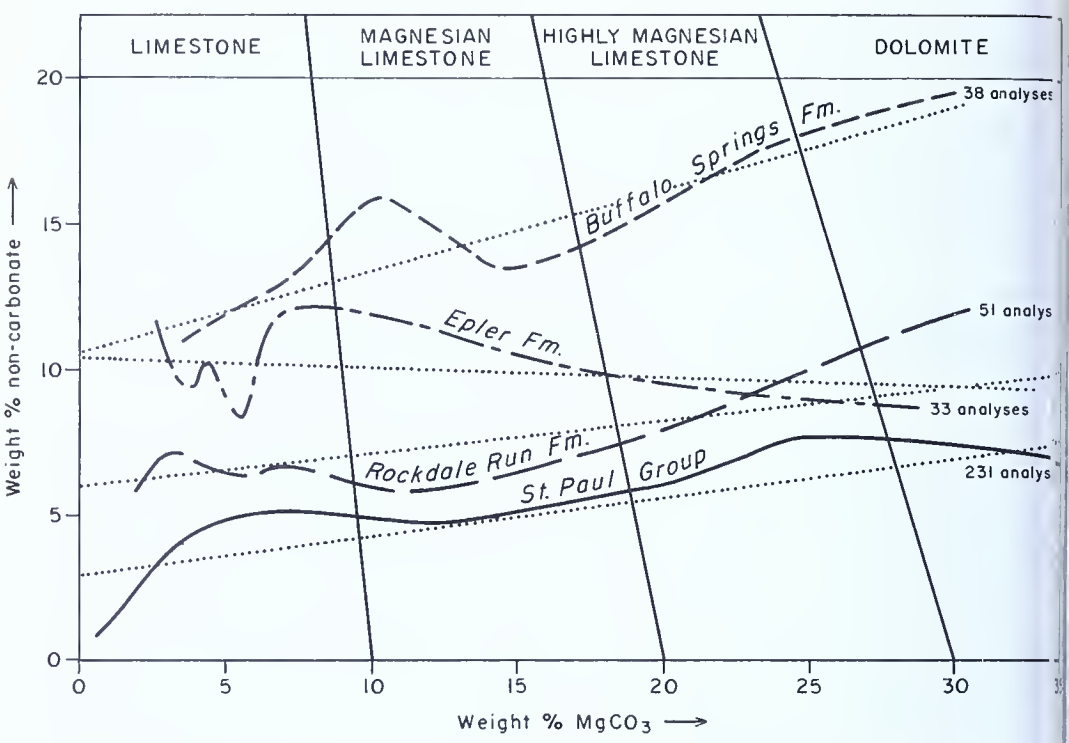


Figure 18. Noncarbonate content as a function of $MgCO_3$ content for four limestone fo mations.

in both properties and highly elongate in the y (noncarbonate) directio in the regions of high density observations. For comparison the curves c Figure 18 have been superposed on the triangular diagrams of the ap propriate formations. It is apparent that the smoothed average differs litt from the trend indicated by the contouring of the St. Paul Group, Figu 23B, which is based on a large number of analyses, but there is mo variability for the other formations, Figures 20A and 21 where individu extreme analyses have more influence. To the extent that the trends di fer as differently deduced, the contouring provides a more realistic pi ture of compositional variation in the areas where there is a fairly hig frequency of observations; but the curves of Figure 18 have several a vantages for evaluating the particular relation in question. They show t average noncarbonate content at any given $MgCO_3$ content abstracte from the number of analyses falling in any given part of the range ar the method provides an objective basis for drawing trends through par of the ranges where there are few observations. The smoothed avera data also provides an objective numerical basis for establishing the bes fit linear approximation of the observed trends. The linear trends sho as dotted lines in Figure 18 were fitted by the method of least squares all points computed in the moving averages. This has the effect of givi

roper weight to the varying number of analyses occurring in different arts of the range.

Several facts about the relationship between noncarbonate and $MgCO_3$ ontent are immediately apparent from a comparison of the curves in igure 18. As previously mentioned in the discussion of stratigraphic ends, the older rocks are shown to be less pure than the younger and ıe Rockdale Run Formation of Cumberland County purer than the quivalent Epler Formation of Dauphin County. As a logical converse is apparent that the generalization associating high noncarbonate with igh $MgCO_3$ content is entirely invalid when applied to the section as a hole; the older limestones are less pure than the younger dolomitic rocks ı the average. The generalization has somewhat more merit as applied individual formations. Three of the four formations do show some verage increase in noncarbonate content with increasing $MgCO_3$; but ıly the St. Paul Group shows a trend permitting the inference that dolo- ıite content is the most important factor influencing noncarbonate (or ce versa). Even in the case of the St. Paul Group the relationship is far om linear. Up to about 3 percent $MgCO_3$, noncarbonate content increases ore rapidly than $MgCO_3$; thereafter it increases only slowly and irreg- arly.

The irregularities of the trends of the Epler and Rockdale Run For- ations in the limestone field are believed to be artifacts arising from the ıance distribution of the small number of analyses available. The rela- ɔn of these irregularities to the actual distribution of analyses is most ɔparent in the triangular diagram for the Epler Formation, Figure 21B. It ems probable that these trends would approximately parallel the other ends in this field if more data were available.

The broad minimum apparent in the Magnesian Limestone field of ıree curves, however, seems to be a real feature. As previously noted, e distribution of observed analyses suggests that, characterized by $MgCO_3$ content, there are two families of rock types represented. The stribution of noncarbonate permits a refinement of this concept. Field ɛamination of actual lithologies show that almost all beds below the ɔpermost impure limestones may be placed in one of five groups:

a) relatively pure calcitic limestones—massive to faintly laminated, apparently by variations in grain size

b) more or less impure calcitic limestones with distinct terrigenous clastic rich laminae—the interlaminae are substantially identical to type *a*

c) magnesian limestone—rarely with a few laminations like type *b* but mostly like type *a*

d) *dolomites* (includes most highly magnesian limestones of analyses)—massive to faintly laminated, apparently variations in grain size

e) mottled limestones consisting of anastomosing rods of magnesian material in a calcitic matrix.

The last group is essentially a mixed type which is apparently the com bined result of organic activity and dolomitization. As it is volumetricall unimportant and probably chemically indistinguishable from group *c,* i will not be considered in the following discussion. The gradation withi and between the other classes define two families which might be char acterized as the laminated family and the magnesian family. On the basi of associations and gradations within individual beds the majority of pur limestone beds of group *a* should be considered as belonging to the lam inated family with group *b* which then accounts for a major part of th compositionally variable formations. The impure rocks of this family d tend to be slightly more magnesian than the purer rocks, but the non carbonate range is large and the $MgCO_3$ range is small giving a very stee trend of variation. The majority of beds which are readily identified wit the magnesian family are concentrated at the high magnesium end c group *d.* As previously observed, there does seem to be a real dearth c analyses in the neighborhood of 20 percent $MgCO_3$; but there does seer to be gradation between the rarer group *c* magnesian limestones and pur limestone of group *a.* In this family the noncarbonate content is distribute throughout the rock body rather than concentrated in distinct lamina There is a gradual increase of noncarbonate as the $MgCO_3$ content ir creases to produce exactly the gradual rising trend predicted by the ger eralization of the noncarbonate dolomite relationship. The two familie thus have a common end member in the pure limestones of group *a,* bu other gradation between them is apparently confined to rare occurrence of clastic laminae of group *c* magnesian limestones. The noncarbonat minimum occurring in the magnesian limestone field of the overall nor carbonate vs. $MgCO_3$ trend is thus the result of the combined influenc of the two compositional families.

The anomalous negative trend in the Epler Formation has a simila explanation. In this case the average limestone of the laminated famil actually has a higher noncarbonate content than the average rock in an part of the $MgCO_3$ range of the magnesian family. This shows up in th overall running average as a regular decline across the magnesian lime stone field because in the limited number of reported analyses there ar actually no observations in the range 10.1 to 20.5 percent $MgCO_3$; th running averages interpolate a smooth join across this gap. With a greate number of analyses the juncture of the fields of influence of the tw families would be more marked, and it seems probable that a minimu in the magnesian limestone field comparable to that in the other forma tions might become apparent.

In conclusion it may be observed that, within a formation of variab composition, on the average the generalization of the affinity of MgC and noncarbonate constituents is valid for the formation as a whole on

beds containing obvious noncarbonate rich laminae are excluded. Furthrmore, the inference of a genetic association between the occurrence of rrigenous clastics and mineral dolomite does seem valid for the rocks haracterized by a uniformly disseminated fine noncarbonate component. he rocks characterized by distinct noncarbonate rich laminae, however, re almost uniformly calcitic; and the depositional environment producig this condition seems to have been antipathetic to significant dolomite rmation.

Iron vs. Dolomite

Iron reported in the chemical analyses is distributed between iron subituting for magnesium in the crystal structure of dolomite mineral grains nd iron-bearing minerals of the noncarbonate portion of the rock. The tter include very small quantities of metamorphic chlorite and possibly etrital biotite, but the most important seem to be detrital (?) iron oxides ith pyrite generally a weak second. To the extent that the noncarbonate mponent has an affinity to dolomite, both factors tend to a relatively igher iron content in the magnesian rocks. On the basis of field obrvations and implied by analyses reporting sulfur the distribution of yrite may, if anything, be a counter-influence but it is not a conspicuous mponent of any rock. By reasoning to be subsequently explained the verage dolomite mineral grain in this area is inferred to have the folwing analysis: $CaCO_3$—54.13 percent, $MgCO_3$—44.93 percent, $FeCO_3$ –0.94 percent. This is within the range of normal dolomite mineral nalyses as reported by Deer and others (1962) and is not notably iron ch.

The relation of total analytic iron, recalculated to $FeCO_3$ when not so eported, to $MgCO_3$ is shown in Figure 19 for the same formations as in igure 18, for all spot analyses reporting iron separately from alumina. he small dots on Figure 19 represent the individual analyses of the St. aul Group. Viewed as a scatter diagram these show a definite positive rrelation between the two components; but there is great dispersion, nd the form of the function is not at all apparent. A running average mparable to that used to reduce the noncarbonate data was computed define the trend. The average values (heavy spots on the diagram) in this ase show that the function is linear to a very close order of approximation. he function was computed by a least-squares regression on the runing average points. The dispersion of the individual analyses of the ther formations is comparable to that for the St. Paul Group. As the rmations become less pure the proportion of total iron that is associated ith the noncarbonate component increases, and the nonlinearity of the oncarbonate trend begins to become apparent in the running averages for on. The Buffalo Springs Formation offers the most extreme example.

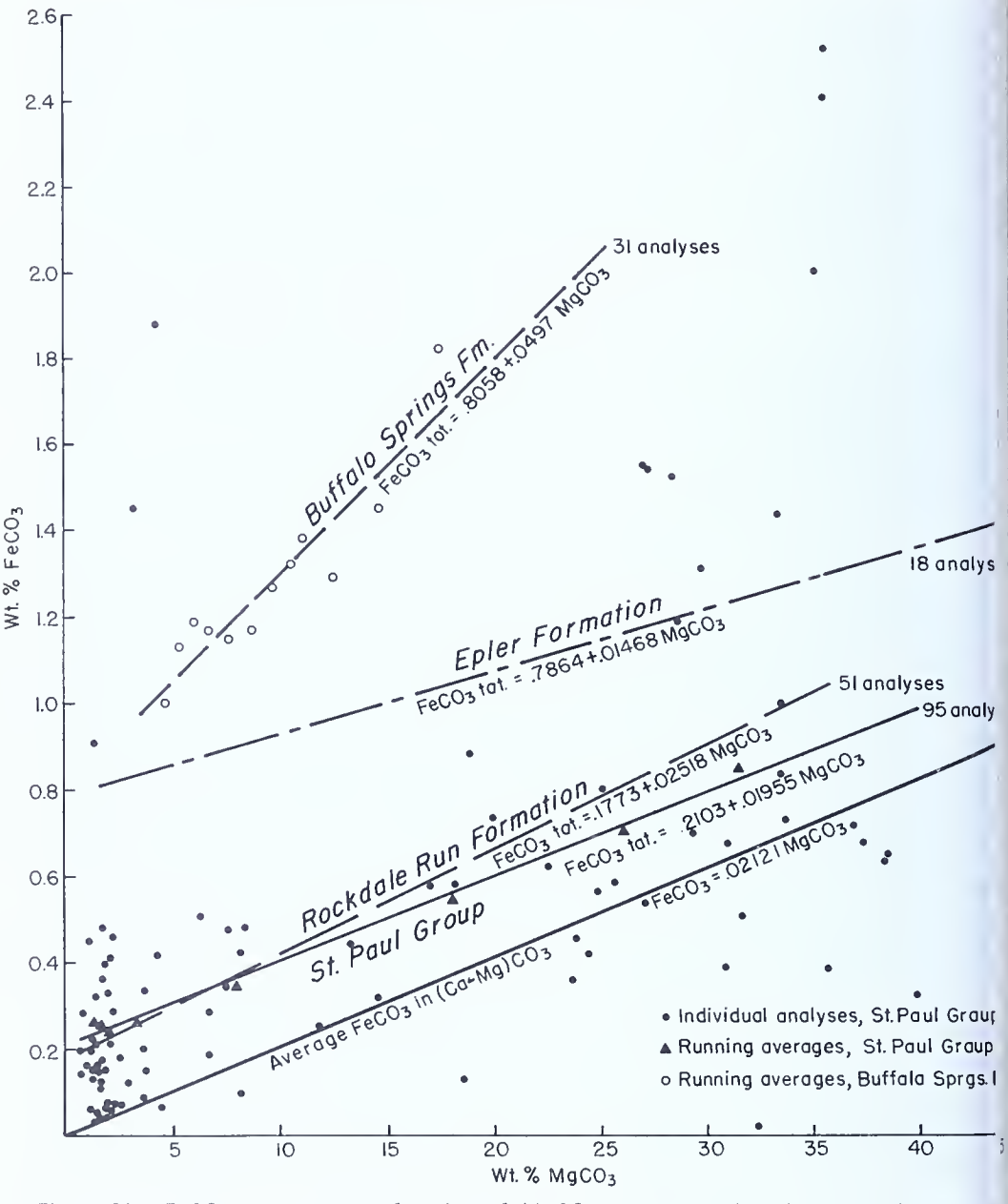


Figure 19. $FeCO_3$ content as a function of $MgCO_3$ content in four limestone formations

These running averages (open circles on the diagram) show a subdued version of the variation in the noncarbonate—$MgCO_3$ trend of Figure 18, but the linear regression still seems to be a good approximation.

The trend of average composition in the System $CaCO_3$-$MgCO_3$-$FeCO_3$ was obtained by correcting the slope of each of the $FeCO_3$-$MgCO_3$ regressions for the slope of the equivalent noncarbonate—$MgCO_3$ regres-

ion. A mean value of these corrected slopes weighted by the number of nalyses contributing to each is considered to be the best estimate of the lope for the average pure carbonate trend. On the probable assumption nat there is no significant substitution of iron for calcium in the carbonate inerals this trend will start at $FeCO_3=0$, $MgCO_3=0$ in the diagram and ise with the slope determined above, as shown by the bottom line in 'igure 19.

The composition of the average pure dolomite end member was ob-ained by converting the weight proportion trend to molecular proportion nd projecting to $CaCO_3=50$, $MgCO_3+FeCO_3=50$ molecular percent. 'he resulting molecular composition was reconverted to the conventional ravimetric analysis.

While the difference in the iron content between the average calcitic nd magnesian rocks is only moderate, and many individual analyses are ar from the trend, the iron content does seem a sufficient explanation of ne marked difference in weathering color if the distribution of the iron ; taken into account. Many of the more impure calcitic rocks of the aminated family actually have higher iron contents than typical mag-esian rocks, but their iron is concentrated in the noncarbonate-rich lam-nae. The result is that these laminae weather yellowish or brown, but the ulk of the rock has the typical neutral to bluish-gray weathering of the alcitic rocks. Among rocks having the more evenly distributed noncar-onate characterizing the magnesian family there does seem to be a fairly egular gradation of intensity of yellowish coloring with increasing $MgCO_3$ rst becoming apparent about at the Magnesian Limestone field. Owing to ne very infrequent occurrence of rock with intermediate $MgCO_3$ con-ent, however, the overall impression is of a distinct partition into gray-veathering limestones and yellowish-weathering dolomites. If the hypothe-is that iron is the principal pigmenting agent on weathered dolomite sur-aces is correct, it may be anticipated that the less pure dolomites with igher iron content owing to increased noncarbonate would show a more ntense coloration than the purer dolomites. This expectation is fully upported by a comparison of typical St. Paul and Epler dolomites, but he Buffalo Springs dolomites are not notably different from those in he Epler in this respect. A plausible explanation for this last relation is that he excess iron is mechanically removed with the other insoluble materials s the particles are liberated by solution of the carbonate.

COMPOSITION OF THE CARBONATE FORMATIONS

Buffalo Springs Formation

The only available chemical analyses (Miller, 1933, and Pa. Geol. Survey 'iles) of the Buffalo Springs Formation are from the vicinity of Corn-

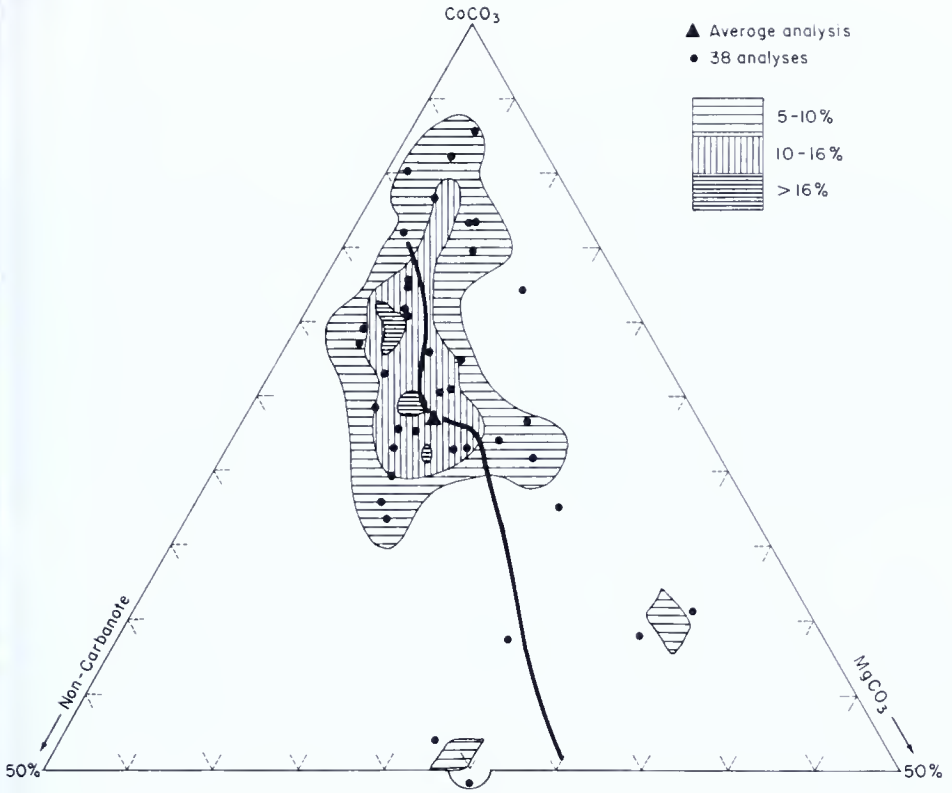
wall, Lebanon County. These analyses are plotted in Figure 20A. Fiel comparison of these rocks with those in Dauphin County indicates tha there is no reason to suppose that Dauphin County rocks of this forma tion would not give a substantially identical major component analysis The notably high iron content of these analyses shown in Figure 19, how ever, may in part be the effect of ore mineralization in the nearby iro deposits. Secondary iron mineralization of this sort should not notabl affect the iron content of the dolomite interbeds, which are apparently primary or early diagenetic feature, but might give rise to an unusua proportion of iron minerals in the noncarbonate fraction.

The only insoluble residue determination made on this formation wa from a 1¼ inch bed which weathered to a porous silty shale. The fres rock was found to give an insoluble content of 64 percent. It was no supposed or intended that this calcareous shale specimen be representa tive of the bulk composition of the unit.

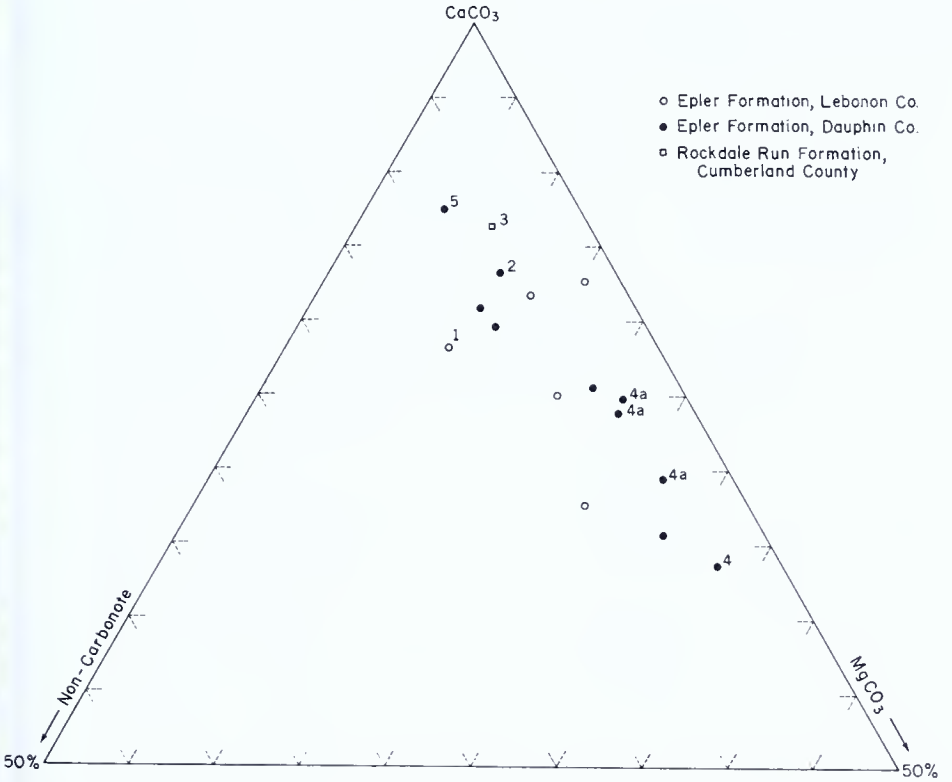
The individual analyses shown in Figure 20A represent both outcro samples and gross analyses of drill holes. In all cases, however, the sampl was intended to be representative of at least a few feet of strata. For thi reason none of the analyses show as extreme a composition as would a full analysis of the specimen on which the insoluble residue determinatio was performed. The implication of thin beds or laminae purer than an of the reported analyses is probably also valid. The contours also show on the triangular diagram effectively summarize the compositional varia tion through the range in which a high density of observations occurs bu the individual analyses are a better indication of the distribution throug the thinly populated magnesian portion of the diagram. The two smal areas above the 5 percent contour in this lower part have no particula significance except to indicate that if sufficient data were available to dra significant contours at the 2 or 3 percent level the pattern would includ a lowest contour envelope extending close to the bottom of the diagram The relationship between the individual analyses and the contoured dia gram is readily apparent in this diagram where both are shown.

The average analysis shown in Figure 20A is simply the unweighte average of all the individual determinations with no implication that eac determination is representative of a comparable volume of rock. Correc tion for the thickness of the sampled units, had it been practicable, migh have given a slightly different bulk composition for the formation as a whole.

The heavy line in the diagram is the smoothed average of noncarbo nate vs. $MgCO_3$ as in Figure 18 shown here for comparison with the con touring.



A. Distribution of analyses from the Buffalo Springs Formotion.



Composite onolyses of Epler ond Rockdole Run Formotions. Numbers on diagrom refer to text.

iure 20. Diogroms of chemicol onalyses of the Buffolo Springs, Epler, ond Rockdole Run Formotions.

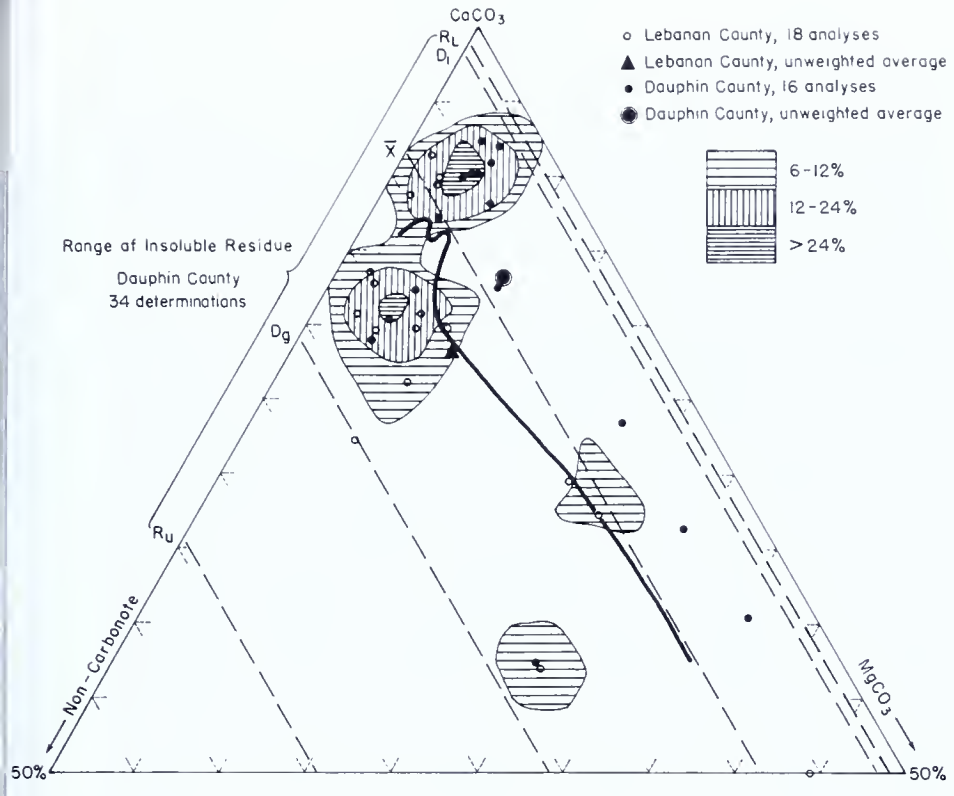
Stonehenge Formation

Few analyses of the Stonehenge Formation are available, and none sufficiently close to Dauphin County to warrant inclusion here. Field observations suggest that the composition is intermediate between the Epler and Buffalo Springs Formations, though probably closer to the former, with exception that there are almost certainly fewer magnesian beds in the Stonehenge than in either of those formations. Insoluble residue determinations on two apparently representative samples of 7.3 and 15.1 percent are consistent with this conclusion but do not represent a sufficient sample to permit any positive inferences.

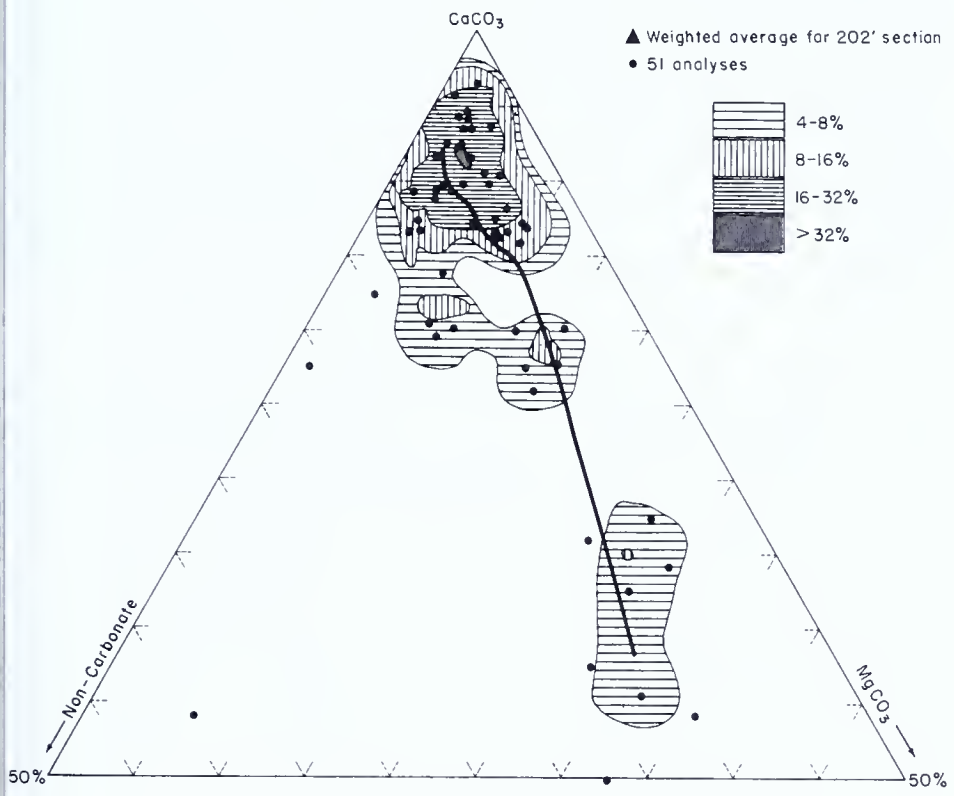
Epler Formation (and Rockdale Run Formation)

The Epler Formation is particularly notable for the variety of its composition. The diagram of Figure 20B shows the considerable range of bulk analyses taken from samples representing the averages of considerable volumes of rock. Some are composites of a number of drill holes or spot samples and others the analyses of quarry products. Figure 21A shows the distribution of analyses of individual beds or small units from one locality in Lebanon County and from three Dauphin County localities. Comparisons of the two diagrams shows that calcitic beds predominate with a subordinate number of quite magnesian beds and none of intermediate composition while the bulk analyses tend toward intermediate values as a consequence of the interbedded character of the formation.

It may be observed in Figure 21A that the distribution of analyses from Dauphin and Lebanon Counties is through a largely overlapping range, but the Dauphin County analyses tend to be lower in noncarbonate constituents on the whole. This effect is very likely the result of bias introduced by the particular purposes for which the limited sampling was performed, but regional trends in lithology deduced from field observations indicate that a real difference of this nature may be expected. The fact that the mean and distribution of 43 insoluble residue determinations is in fairly good agreement with the average analysis and variation of the Dauphin County analyses supports the conclusion that the reported analyses are fairly representative of the overall composition in the County. The average (unweighted) analyses of Figure 21A are also shown as points 1 and 2 on Figure 20B. Point 3 of Figure 20B represents the weighted average of the analyses of the Rockdale Run Formation from Cumberland County shown in Figure 21B. While the whole thickness of the formation has not been systematically sampled in any of these three averages, the overall change in composition along strike showing decrease of both noncarbonate and magnesia toward the southwest implied by the lithology is confirmed by the available chemical data.



A. Distribution of analyses from the Epler Formation.



B. Distribution of analyses from the Rockdale Run Formation.

Figure 21. Diagrams of chemical analyses from the Epler and Rockdale Run Formations.

The composite analyses of Figure 20B with extreme composition rang represent special situations that are not very representative of the form tion as a whole. Point 4 in this figure is the average analysis of shipmen of magnesian fluxstone from the Bethlehem Steel Quarry at Steelton. Th stone is the product of selective quarrying blocked out by chemical analys in a manner calculated to raise the magnesia and reduce the noncarbona with respect to the bulk composition of the rock in this area. The poin labeled 4a are composite analyses from the general area which is dispr portionately represented among the analyses of Figure 20B tending create an impression of a greater proportion of relatively pure magnesia rocks than is actually valid for the formation as a whole. Point 5 is th average of a number of drill holes east of Swatara Creek near Fiddler Elbow. These holes are in a particularly pure and limy looking area of th lower part of the Epler Formation which was presumably prospected fo its unusually inviting character. In each of these cases there seems to b a considerable volume of rock of these rather extreme bulk analyses i the particular areas in which they occur, but the intermediate bulk analys are more representative of the formation as a whole.

The dark lines in Figure 21 are the smoothed average of noncarbona vs. $MgCO_3$ as plotted in Figure 18 shown here for comparison with th distribution of analyses. While the contouring in these figures is probab a fairly good approximation of that which would be obtained from much larger sample throughout most of these diagrams, the isolated percent contour extending into impure dolomite field of Figure 21A probably an example of a "noisy" contour arising from the chance nea coincidence in a small sample of two observations having a relatively lo probability of occurrence.

Ontelaunee Formation

Lower portion.—The lower Ontelaunee Formation is gradational int the uppermost Epler Formation where the chert marker beds at the bas of the Ontelaunee are absent, as is the case through most of Dauphi County. This gradation takes the form of a fairly rapid upward increas in the proportion of magnesian beds and a virtual disappearance of th terrigenous clastic laminated limestone beds which are abundant throug most of the Epler Formation. The limestones with disseminated noncar bonate minerals and the magnesian-mottled limestones continue with abou equal abundance from the Epler to the Ontelaunee Formation. In thi situation it would be anticipated that the individual bed analyses woul show generally the same pattern as the Epler Formation with a relativel higher proportion in the magnesian fields and fewer in the impure lime stone field. The composite bulk analysis might be expected to lie not to far from the typical Epler analyses but tending toward higher magnesi

ad lower noncarbonate. The only available analysis (not plotted—see Miller, 1934) is a run-of-quarry analysis from Cleonia, Lebanon County. This analysis lies in the range of, and is essentially indistinguishable from, the intermediate analyses of the Epler Formation in Figure 20B.

Upper member.—The upper member of the Ontelaunee Formation exposed in the hanging wall of the major Annville Limestone quarries, and extending through at least most of the Annville-Ontelaunee contact area, is essentially composed of a heavy bedded, pure dolomite. Some of the beds are separated by stylolite seams that locally contain more than an inch of dark argillite; interbeds of high-calcium limestone are occasionally present. The analyses shown in Figure 22 by the triangular symbols are all composite analyses which should be representative of a considerable volume of rock including a proportionate quantity of the stylolite partings and limestone interbeds. The purity and low variability makes the composition of this unit of particular interest. The actual analyses are shown in Table 1.

The observed range of insoluble residues represents only four samples and may include a specimen from the lower part of the formation which

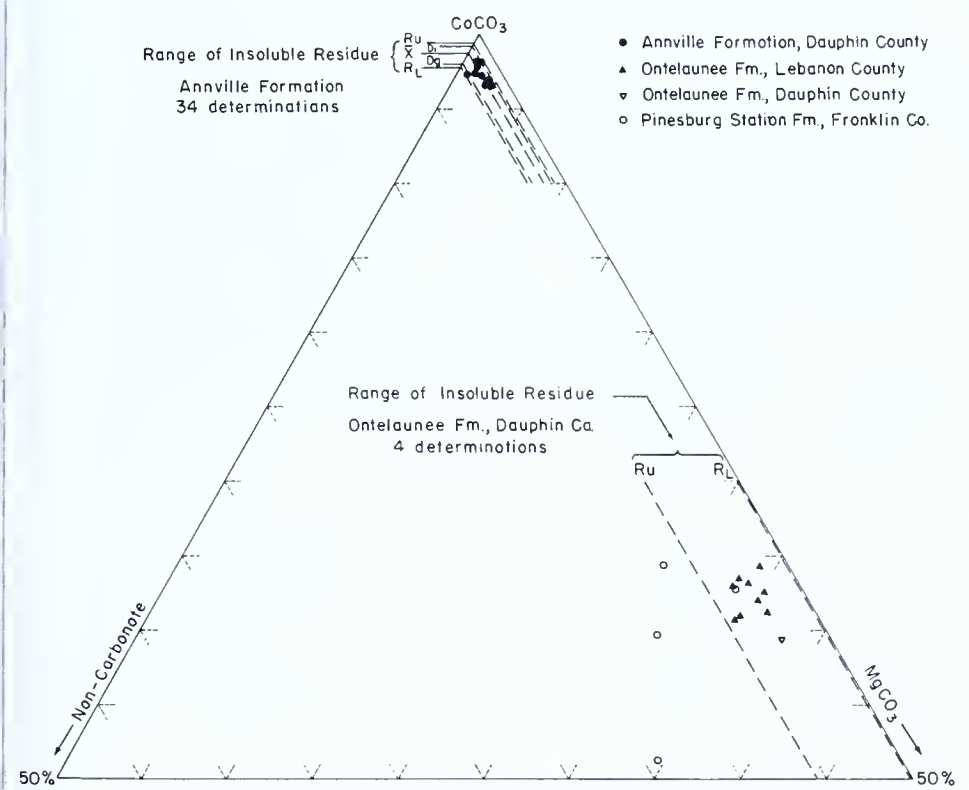


Figure 22. Composite analyses of Annville, Ontelaunee, and Pinesburg Station Formations.

Table 1.—*Analyses of upper Ontelaunee Formation in Dauphin and Lebanon Counties*

	1	2	3	4	5	6	7	8	9	10
$CaCO_3$	62.65	63.39	62.95	63.06	61.13	61.95	64.16	59.33	60.69	60.
$MgCO_3$	35.15	33.28	33.22	34.00	36.12	35.14	34.14	37.20	34.38	34.
SiO_2	1.31	2.12	2.42	1.72	1.42	1.21	1.10	2.32	3.11	2.
Al_2O_3	0.16	0.35	0.20	0.20	0.20	0.28	0.28	1.16	1.82	2.
Fe_2O_3	0.73	0.86	1.21	1.02	1.13	0.69	0.41			

All analyses recalculated to 100%

is less conspicuously pure. The exceptionally low 0.1 percent determination is from a shear-mottled limestone bed indistinguishable in hand specimen from the sheared beds sometimes present at or near the base of the Annville Formation, but it is even purer than those rocks.

Pinesburg Station Formation

The four analyses shown by open circles in Figure 22 are from the uppermost part of the Beekmantown Group in Franklin County (Swartz and Thompson, 1958). This is too far from Dauphin County to permit much confidence that they closely approximate the composition of the Pinesburg Station dolomite in this area. On the other hand there is a remarkable consistency of general aspect to those rocks throughout the Cumberland Valley and a distinct difference between these rocks and their correlatives in the Lebanon Valley. The Franklin County analyses, though remote, may at least be suggestive of the differences in composition that the physical differences from the Ontelaunee Formation imply. To the extent that these analyses are valid for Dauphin County they indicate that the Pinesburg Station dolomites tend to be somewhat more calcitic or limestone interbedded and distinctly less pure than the upper Ontelaunee dolomites. Cherty horizons occurring at several levels within the Pinesburg Station may account for the particularly high noncarbonate of one analysis.

Annville Formation

Nine analyses of the Annville Limestone, including five new analyses obtained for this report, are shown in Table 2, and plotted as solid circles on Figure 22. The location of these analyses are shown by arrows on Figure 25. All the analyses except number 1 are composites attempting to show the value of a considerable body of rock. Field examination suggests that a few beds in some localities might fall outside the high-calcium limestone field but all the composite analyses are well within it.

In view of the small observed range, the 34 insoluble residue deter-

Table 2.—*Analyses of the Annville Limestone in Dauphin County*

	1	2[1]	2a[2]	3[1]	3a[2]	4[1]	4a[2]	5[1]	5a[2]	6[1]	6a[2]	7	8	9[3]	9a[4]
$CaCO_3$	97.24		96.53		97.93		96.64		96.77		97.18	97.6	98.02	98.50	97.94
CaO		55.05		99.91		55.20		55.05		55.45			0.00		
$MgCO_3$	0.50		2.37		0.92		2.05		1.94		1.52	1.1	0.70	1.10	1.09
MgO		1.15		0.45		1.00		0.94		0.74			0.27		
SiO_2	2.012[5]	0.80		0.76		0.92		0.77		0.87		0.9	0.46	0.35	
Al_2O_3	0.185	0.20		0.26		0.28		0.34		0.31		0.4	0.51	0.27	
Fe_2O_3		0.09		0.12		0.12		0.16		0.12			0.09	0.06	
S		0.010		0.008		0.010		0.010		0.018			0.001	0.053	
CO_2		42.65		42.35		42.45		42.65		42.43				(43.09)	
P_2O_5		0.018		0.014		0.009		0.027		0.009			0.00X	0.0021	
total non-carbonate	(2.26)		1.10		1.15		1.31		1.29		1.30	(1.3)	(1.28)		0.97
	99.94	99.95	100.00	99.91	100.00	99.99	100.00	99.95	100.00	99.95	100.00	100.00	100.05X	100.575	100.00

Values in parenthesis are redundant and not included in totals

Notes

[1] Analysis as reported

[2] Reported analysis converted to theoretical carbonate and recalculated to 100.00%

[3] Analysis as reported, includes 0.115% Na and 0.078% K in total

[4] Reported analysis recalculated to 100.00%

[5] High SiO_2, probably result of small quartz-calcite veins

minations are probably sufficient to constitute a good representative sampl of the formation in Dauphin County. The insoluble residues reinforce th conclusion of the well-distributed analyses that the Annville Forma tion as a whole is a good high-calcium limestone wherever it appears i the county. A factor not apparent in the analyses but determined by ig nition of the insoluble residues is that a substantial fraction (15 to 3 percent in three determinations) of the total noncarbonate as thus deter mined is organic carbon.

Saint Paul Group

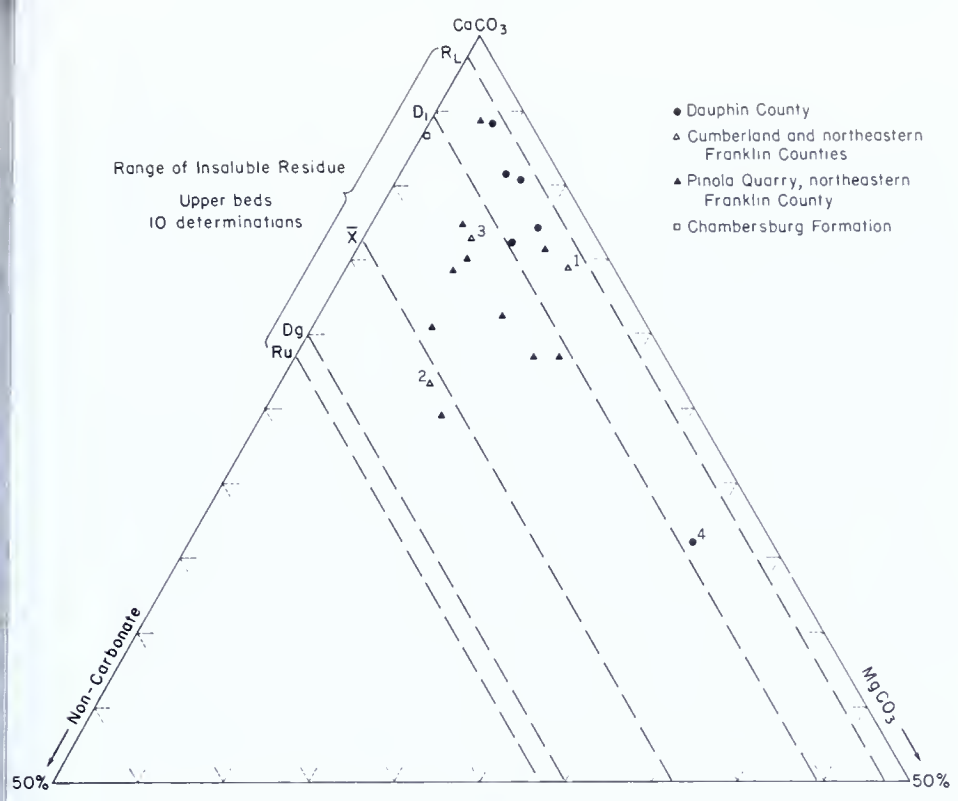
Lower St. Paul Group of the Principal Crop Area

The St. Paul Group as represented in this area is rather similar to th Epler Formation in that it is typically expressed as predominant lime stone beds, some with terrigenous clastic laminae, and subordinate highl magnesian interbeds and relatively rare beds of intermediate composition Figure 23B shows the result of a bed-by-bed analysis of a 321-foot sec tion on the west side of the Susquehanna River (Cumberland County) op posite South Harrisburg given in the Appendix as Section 2a. The sam beds are also exposed on the east side of the river and apparently consti tute a large portion of the cropping strata in much of the area in whic the St. Paul Group is mapped in Dauphin County. For this reason thes analyses, though from just outside the County, are thought to be a re liable indication of the composition of much of the St. Paul Group within the county. It may be observed that the analyses in general, and notabl the calcitic ones, are purer than those of the Epler Formation; and the transition between calcitic and magnesian rocks is more apparent.

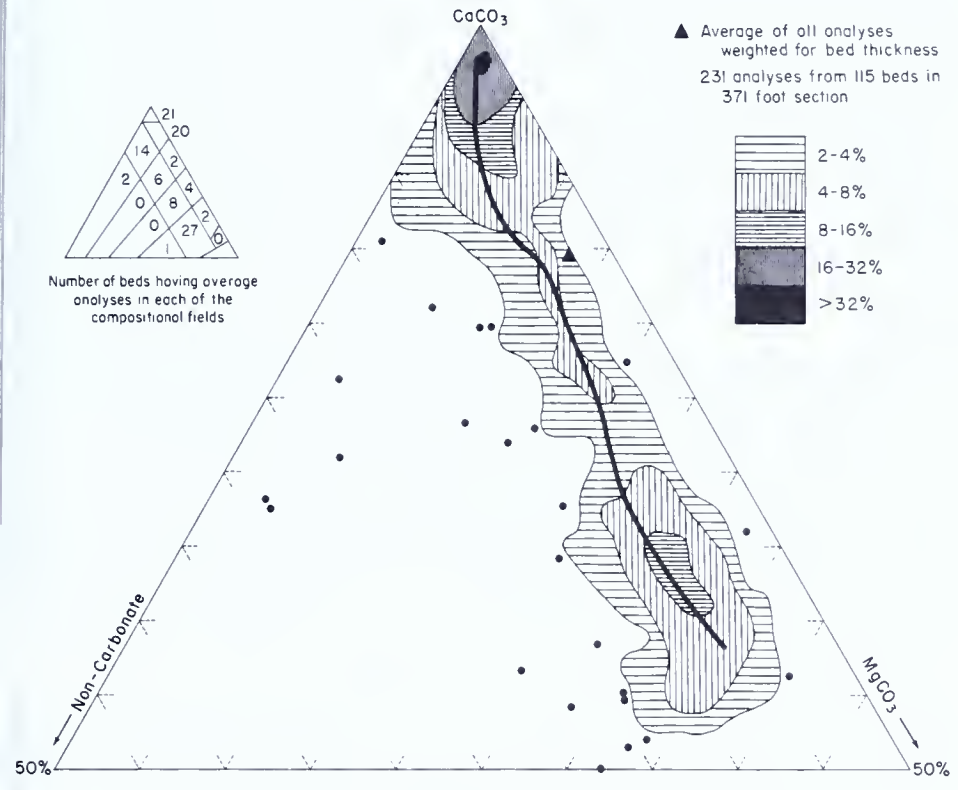
In this diagram only analyses lying outside the lowest contour, repre senting about 9 percent of the total, have been individually shown. Within the contoured area the density of observations is such that an attempt to show individual determinations would only be confusing. Of the deter minations lying outside the contoured area the majority lie close to the lowest contour and represent merely the more extreme values along the main contoured trend. The only probably significant arrangement of points that departs much from the contours is the scattering of points well into the impure limestone field which represents the more extreme members of the terrigenous clastic-laminated limestone group. This subordinate trend is almost certainly real but is not apparent at the 2 percent level beyond 12 percent noncarbonate.

The heavy line of Figure 23B is the smoothed average of noncarbonate vs. $MgCO_3$ from Figure 18 presented here for comparison with the con tours.

The average analysis of the section of Figure 23B, weighted for bed thickness is shown as point 1 in Figure 23A. All the Dauphin County analyses shown in this figure are bulk analyses of quarries at about the



A. Composite analyses, numbers on diagram refer to text.



B. Distribution of bed analyses in Lemoyne quarry.

Figure 23. Diagrams of chemical analyses of the St. Paul Group.

same stratigraphic level as the Susquehanna River analyses, except poir 4 from the Hempt Brothers Quarry at Paxtang which may include som lower beds. These average analyses are somewhat more calcitic than th weighted average analysis of the Susquehanna River section as the resul of deliberate selection in quarry location.

The single insoluble residue determination definitely made from thes beds of the St. Paul Group was 2.7 percent from a fairly typical high calcium limestone bed of the sequence which was quite similar in gros aspect to beds in the Annville Formation. This value is entirely consisten with the analyses of the St. Paul section shown in Figure 23B but twic that of average Annville limestone and falls above the 90th percentil of impurity (Dg of diagrams) in the Annville range. The color of thi residue, while darker than most of those obtained from higher St. Pau (?) beds, suggests considerably less carbon than any of the Annvill residues.

The beds probably in depositional continuity above the section fron which the Dauphin County analyses and the Cumberland County analysi of point 1 were taken may be somewhat less pure. Point 3 of Figure 23A is a composite weighted for bed thickness from 181 feet of strata (Pa Geol. Survey files—courtesy of Hempt Bros., Inc.) from the Hemp Brothers Quarry at Eberly's Mills, Cumberland County, less than 2 mile from the section of point 1 but probably several hundred feet stratigraphi cally higher. Beds equivalent to these may be present toward the south ern end of the exposures on the east side of the Susquehanna. Point 2 of Figure 23A is a run-of-quarry analysis reported from the Pinola Quarry in southeastern Franklin County by O'Neill (1964) who judged the quarry rock to be possibly Chambersburg Formation on the basis of analysis and reported location. A recently available consultant's report (Pa. Geol Survey files—courtesy of Valley Quarries, Inc.) shows the rock quarried to be entirely in the upper part of the St. Paul Group, presumably above any strata represented near the Susquehanna River with the possible exception noted below. The small triangles on Figure 23A represent composite analyses of operationally significant stratigraphic intervals from 14 to 82 feet thick. These analyses show purer stone than the run-of-quarry analysis reported in 1963 but still indicate higher impurity than reported lower in the St. Paul Group.

Upper St. Paul Group (?) of Thrust Slice

Rocks of uncertain stratigraphic position discontinuously exposed in a slice dragged in the sole of the Yellow Breeches thrust on the south side of the Harrisburg-Rutherford belt of carbonate outcrop were tentatively assigned to the upper St. Paul Group on the basis of gross lithology and probable chemical composition inferred from insoluble residue determina-

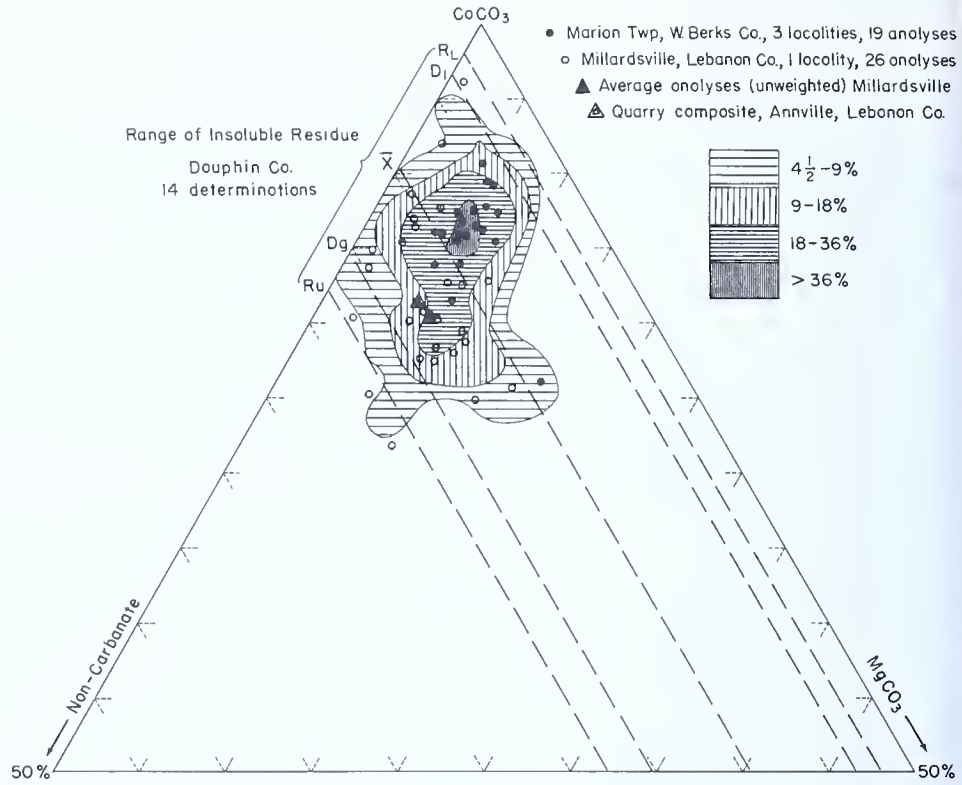
tns and field descriptions. Ten insoluble residue determinations fom these rocks are summarized in Figure 23A. They were obviously dawn from a less pure sequence of beds than is represented by the Dauphin or Cumberland County analyses of rocks in the main outcrop elt. The insoluble residues are light-gray, abundantly quartz silty, and ery low in carbonaceous material. They form a distinctive group quite unlike any others encountered in this study above the middle Epler Formation. Field descriptions note that dolomite is not frequent in these rocks; hence the probable analysis would be high in insoluble constituents, notably silica, and relatively low in magnesia.

The analyses from upper St. Paul Group quarries at Pinola mentioned in the previous section meet the requirements of the inferred analysis of the thrust slice rocks more closely than those of any other structurally and lithologically plausible unit. The run-of-quarry analysis of point 2 in Figure 23A is particularly suggestive in that the total noncarbonate is very close to the mean ($\overline{X}$) value of the insoluble residues of the Dauphin County rocks. The strata represented by the small triangles are somewhat purer; but, of the 58 individual analyses used in defining the quarry units, only three beds show a highly magnesian limestone composition. Most beds do show significant magnesian contents yielding higher magnesia for the section as a whole than might be inferred from field descriptions. In view of these similarities to the inferred composition of the thrust-slice rocks, it seems probable that the analysis of point 2, Figure 23A is a good approximation for analysis of the Dauphin County rocks.

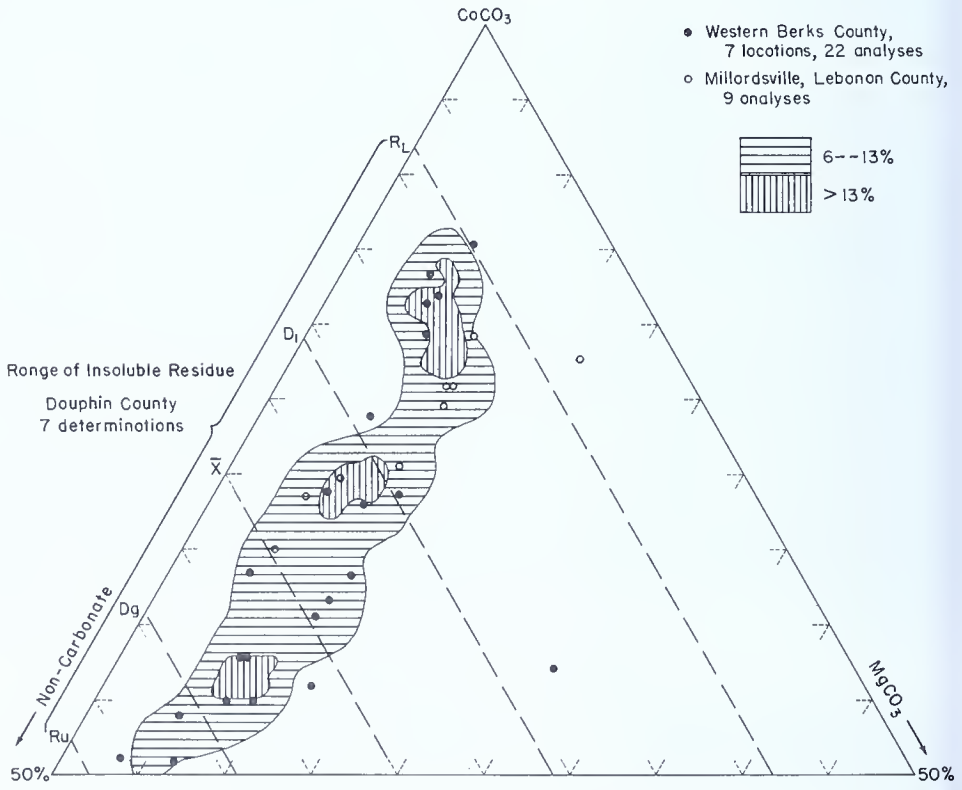
Comparison of the inferred composition and insoluble residue percentages with the other units for which analytic data are available shows that only the Myerstown Formation (Figure 24A) is generally similar. The heavy-bedded character and gross aspect of upper St. Paul Group (?) is entirely different from the Myerstown or its tectonically more plausible correlative in the Cumberland Valley sequence, the upper Chambersburg Formation. The only available Chambersburg analysis (O'Neill, 1964, location number 265) shown as a cross on Figure 23A is also notably less magnesian and purer than either of the other two formations, though a trend toward increasing magnesia and noncarbonate northeastward would be consistent with that in the underlying rocks.

Myerstown Formation

While there are no analyses of the Myerstown Formation available from within Dauphin County, the insoluble residue data indicate that the composition is about the same as in Lebanon and westernmost Berk Counties. The individual analyses shown in Figure 24A suggest that there might be a trend of compositional change westward from Berks County, but the insoluble residue data from Dauphin County do not support this



A. Distribution of analyses from the Myerstown Formation.



B. Distribution of analyses from the Hershey Formation.

Figure 24. Diagrams of chemical analyses of the Myerstown and Hershey Formations.

onclusion. It may be observed that the analyses reported from Marion ownship of western Berks County ("Upper Annville," of Gray, 1951) re on the whole purer and distinctly less variable than the analyses f the Myerstown Formation at Millardsville. The unweighted average f the Millardsville analyses is very similar to the analysis shown by Miller 1934) in the Myerstown of the Annville area suggesting that the Leba- on County Myerstown Formation might be distinctly different from that n Berks County. On the other hand, the Dauphin County insoluble resi- ue determinations, while they indicate a compositional variability sub- tantially identical to that shown by the Millardsville analyses, have a nean value substantially purer than the average noncarbonate of the Leb- non County analyses. In fact the 10.1 percent mean noncarbonate of the ombined Lebanon and western Berks County analyses is not statistically lifferent from the Dauphin County mean insoluble residue within the imits of the available data. For this reason it is believed that the con- ours of Figure 24A based on the combined analyses, are a reasonably good pproximation of the distribution of analyses to be anticipated in the My- rstown Formation of Dauphin County.

Hershey Formation

The majority of available analyses for the Hershey Formation are those eported by Gray (1951) as Jacksonburg in the areas where "upper Ann- ille" (Myerstown) Formation also occurs in western Berks County. A ew analyses also apparently from the Hershey Formation have been ob- ained from the Millardsville area in Lebanon County which are generally onsistent with the Berks County analyses, as shown in Figure 24B. The even insoluble residue determinations from Dauphin County cover ap- roximately the same range. As the field aspect of the lithology changes ery little from Berks County to Dauphin County above the local basal onglomerate member, it seems reasonable to suppose that the overall nalyses of the rock change little through this distance. It is apparent on he diagram that the Dauphin County insoluble residue samples may have een drawn from a group of beds with slightly higher noncarbonate con- ent than those represented by the Lebanon and Berks Counties analyses, ut otherwise it seems reasonable to anticipate that Dauphin County nalyses will show about the same distribution as shown in the figure.

USES OF THE DAUPHIN COUNTY LIMESTONES

GENERAL REMARKS

The uses of carbonate rocks divide broadly into two classes: those de- pendent on the bulk physical properties as a conveniently available rock material, and those in some way dependent on the chemical properties of the rock. The volumetrically most important use of carbonate rocks is as

structural material. In former years a substantial quantity was used in blo form for building stone, but concrete construction has entirely restrict this use to certain ornamental stones never quarried in this area. The u of crushed limestone as a concrete aggregate is very extensive, howeve and constitutes the largest single use. A considerable quantity of crush limestone and dolomite is also employed in such related uses as railw ballast, road metal, roofing, etc.; but the specifications generally do n exceed those for concrete aggregate so that a stone suitable for this u will also serve the others. For this reason the success of any gener crushed stone operation essentially depends on its ability to produ suitable aggregate. In these applications the composition of the rock of no importance as long as objectionable quantities of particular und sirable constituents are not encountered. Cryptocrystalline and hydro silica (opal, chert, flint, jasper, etc.) react with cement paste and can tolerated only in very small quantites. Excessive pyrite and other iro bearing minerals may produce objectionable stains on weathering. Neith of these presents a major problem in the use of the Dauphin County ca bonates. More prevalent noncarbonate constituents of the rock prese no particular difficulty. Indeed, impure carbonates frequently are tough aggregates than the purer ones.

The use of carbonate rocks as aggregate depends essentially on a ceptable physical properties and low price. It is everywhere in compet tion with other materials that meet the same requirements. In Dauph County, slag and washed river gravels are used for the same purpose, ar various other natural and artificial products are employed elsewhere. A a suitable limestone or some alternative product can be found in almo any region where the need arises, and aggregate must be a high-volum low-cost material, it is rarely economic to ship it any great distance. I some instances it may be desirable to open a quarry close to a majo construction project in preference to using an established supply only few miles away. For this reason evaluation of potential aggregate su plies must be made in terms of a limited marketing area.

There are a few specialized uses of carbonate rocks, such as miner fillers, for which physical properties are technically the controlling facto but the requirements are so severe that the composition is quite as critic as in most applications controlled by the chemistry of the rock. The pr ducers of such products, therefore, are usually specialists whose princip products are graded for compositionally controlled uses.

The uses of carbonate rocks essentially dependent on their compos tion are too numerous and varied to be entirely encompassed within th scope of this text. The critical characteristics vary widely in type an rigor depending on the particular use. The volumetrically most importar uses in this area have been cement manufacture (high-calcium limeston

ir admixture with $CaCO_3$-deficient rocks only), agricultural lime and lnestone, various grades of chemical and structural lime, and metal-lrgical flux. The last of these uses has considerably declined in this area ving to the cessation of local pig iron production, but shipments of lect stone have been recently made to steel producers outside the area. ne requirements for agricultural stone are not particularly severe. Gen-ally anything over 85 percent total carbonate may be sold in the local arket. The crushed or ground undersized material of aggregate pro-icers is often marketable for this pupose. Burned and hydrated agri-ltural lime of greater purity can be economically shipped greater dis-nces, but this market is only regional at best. The demand for cement-riching limestones produced in this area varies from time to time as its mpetitive position with respect to alternative supplies changes, but a ntinuing demand from eastern Pennsylvania cement producers seems obable. The higher grades of chemical lime and limestone compete with much smaller number of alternative sources than any other carbonate oduct actually or potentially produced in this area. For this reason they ay be economically shipped considerably greater distances than any her. Though the tonnages involved in some of these uses is relatively nall, in most cases the producer must be in a position to guarantee a ntinuing supply of high and uniform quality. It is, therefore, a difficult arket for a small or new producer to enter.

Dauphin County is well supplied with carbonate rocks for most pur-ses. The major part of the section contains rocks suitable for aggre-te and most or all of the other structural and related uses of limestone. very formation except the Hershey Formation has been worked at one ne or another as a local source of agricultural lime, and most of these rmations contain at least certain areas which would yield an acceptable oduct even by present standards, though not all are likely to be eco-mic. The rocks suitable for more specialized uses having definite com-sitional requirements are naturally more limited. The area, however, has ways been sufficient to its own needs and some products enjoy quite a ide market.

The use of a given block of stone depends, of course, on other factors sides the physical properties and chemical composition of the rock. he outstanding factors are the cost of recovering and transportation rela-ve to alternative sources of supply, particular problems that may be ncountered in recovery, and the relative value of the land as a quarry nd in alternative uses. It is not the general intention of this paper to nsider these essentially nongeologic factors for various areas of the unty, but there are certain distinctions of this type that are more or ss valid for formations as a whole which should be mentioned in the valuation of the various formations.

EVALUATION OF FORMATIONS BY USE

Buffalo Springs Formation

The Buffalo Springs Formation is extensively used as a source of ag gregate in the Cornwall area, Lebanon County. The rocks of this forma tion exposed in Dauphin County are sufficiently similar to suggest tha they might also be suitable, with certain reservations. The Dauphi County rocks are more highly cleaved than those at Cornwall and have tendency toward the development of phyllitic, easy-parting surfaces i the cleavage direction. The effect is to produce a marked tendency towar slabby fracture which may give rise to crushed stone in which the par ticles do not have the desired equant dimensions and have insufficien crushing strength, particularly in the larger sizes. As the crop of th formation is limited to the southeast corner of the Dauphin County lime stone area, alternative sources, some presently exploited by establishe producers, are more advantageously situated with respect to the principa markets.

The composition diagram, Figure 20A, shows that the bulk composi tion and variability are such that the Buffalo Springs Formation is no suitable for any use where composition is an important factor. It is pos sible that ground agstone acceptable for local use might be profitably pro duced from this formation in conjunction with a general crushed ston operation; but it is probably not practicable to work the Buffalo Spring Formation for this product alone.

In view of the doubtful quality and the disadvantageous location i would appear that the Buffalo Springs Formation in Dauphin County does not have any significant potential for economic exploitation at the present or in the reasonably projectable future.

Stonehenge Formation

There is no known active production of the Stonehenge Formation anywhere in the Lebanon Valley. Formerly the shaly, laminated beds were extensively used as a building stone; but the parting along the laminae, which facilitated producing squared blocks, is undesirable in an aggregate material. While no useful chemical analyses are reported, as remarked in the discussion of composition, the lithology indicates the anticipated analyses would show a relatively impure variable rock. There is no positive indication that an acceptable aggregate could not be pro- duced from parts of the formation, but exploitation is under essentially the same disadvantage of location as the Buffalo Springs Formation. It does not seem probable that production from the Stonehenge Formation will ever be competitive with alternative sources in the area of rock of comparable or superior quality.

Epler Formation

The Epler Formation is an important unit across the entire county and has been a major source of crushed aggregate. It is presently quarried for this purpose just east of the county at Palmyra by the Millard Lime and Stone Company, and at the western edge of the county at Steelton by the Bethlehem Limestone Company. Highway Department tests (Anon., 1961) of the Bethlehem operation indicate the following: Specific gravity 2.74, Percent absorption 0.28, and Daily tonnage 1500. Crushed stone has been produced at various other quarries between the presently active ones, but all are now abandoned. There are, however, substantial reserves of material apparently comparable to that being actively produced which could be made available if demand warranted.

A substantial quantity of metallurgical flux has also been produced from the Epler Formation. As may be seen in the compositional diagrams, Figures 20B and 21A, the composition is quite variable; but, with carefully controlled quarrying, fluxes of fairly high and intermediate magnesia content may be produced from areas such as at Steelton where concentrations of particularly pure rock are found. Flux production has substantially declined with the cessation of local demand, but shipments of the higher magnesium grades have been made to mills outside the area.

In the past, numerous small agricultural lime operations were scattered through the Epler crop area, but the agricultural demand is now met by ground by-products of aggregate operations and large producers working more uniform formations.

The long-term prospects suggest that the Epler will be a continuing and increasingly important source of aggregate and related products, but substantial use for other purposes is not anticipated. Increasing urbanization will both provide demand and effectively eliminate some of the presently competitive alternate supplies.

Ontelaunee Formation

The lower Ontelaunee Formation is generally similar to the adjacent Epler. To the extent that it is more dolomitic it may yield a tougher, hence even more desirable, aggregate. The basal chert beds are not well developed in Dauphin County, but should be avoided, if present, as an objectionable contaminant. The uppermost beds of the Ontelaunee Formation are particularly dolomitic. They make entirely satisfactory aggregate but may ultimately prove to be more valuable in other applications. Aggregate is presently produced from the upper and middle (?) parts of the formation along Swatara Creek by George Ebersole and Sons, Co. for which the State Highway Department (Anon, 1961) gives the following data: Specific gravity 2.79, Percent absorption 0.64, and Daily tonnage 800. The Pennsylvania Supply Company is currently developing an oper-

ation north of Hummelstown to work the lower Ontelaunee beds with a planned 2000 tons per day plant capacity. The H. E. Millard Lime and Stone Company produces a considerable tonnage of the upper Ontelaunee in the process of the operations on the Annville Limestone in eastern most Dauphin County and adjacent Lebanon County. The bulk of this stone is sold as aggregate or used in their own ready-mix concrete business.

The prospects of future development in the lower Ontelaunee Formation seem about the same as for the Epler. The upper Ontelaunee Formation, however, about 100 feet or more of beds where fully developed, has potential as a source of high quality magnesian stone which has not been fully exploited to this time. The presently available analyses do not indicate whether the phosphorus and sulfur content of this unit will exceed the critical low maxima allowed for these components in modern steel making practice, but otherwise these beds seem to be of a composition increasingly sought by the steel industry. The sources of high magnesium metallurgical grade stone are not as widely distributed as those for more calcitic stone, and magnesian flux is sometimes shipped considerable distances. Dauphin County might enjoy a favorable situation for shipment to Pennsylvania and Atlantic Coast steelmakers. The analyses of Table 1 suggest that the unit as sampled has a quite acceptable bulk analysis. At least some of these analyses include argillaceous partings which develop on stylolitic bedding planes. Examination of coarse aggregate of approximately the size that would ordinarily be used in fluxing indicated that the bulk analyses of this product is probably somewhat upgraded by the simple crushing and screening process. The contribution that these argillaceous partings make to the noncarbonate content is largely concentrated in the finer screenings.

The fact that the upper Ontelaunee Formation occurs directly adjacent to the Annville Limestone makes the possibility of blending the two units for particular purposes especially attractive. Some of the older bulk quarry analyses of fluxstone shipments from the Annville belt indicate that operators informally used to sell to the steelmakers as much of the hanging wall rock as they would take with the high-calcium stone, but deliberate blending to achieve controlled calcium-magnesium ratios is not generally employed. An obvious prospect for such blending would be high-grade agricultural limes of controlled magnesia content. The locally preferred liming material has been a high-calcium lime produced from the Annville Limestone, but modern agricultural research indicates magnesia as a plant nutrient is highly desirable in many cases. Blending of the upper Ontelaunee with the Annville would provide the constituent with a very modest increase in noncarbonate content. Limes with some magnesia content are also acceptable or preferred for certain industrial applications.

Pinesburg Station Formation

While there is no indication that the Pinesburg Station or other Beekmantown rocks of the Cumberland Valley sequence would not make acceptable aggregate and possibly be suitable for some other uses, no development is to be anticipated in Dauphin County. The outcrop area is small and generally covered by a thick overburden of Martinsburg shale clash. In addition the entire crop area underlies urban and rapidly developing suburban real estate where quarrying would be exorbitantly expensive if not prohibited by zoning regulations.

St. Paul Group

The St. Paul Group has been an important source of crushed stone and fluxstone in the Harrisburg area. Fluxstone production has been entirely discontinued for some time and is unlikely to be resumed. While considerable quantities of stone having bulk analysis comparable to the better analyses shown in figure 23A are probably still available for development, these are neither the extremely pure nor highly magnesian types for which steel producers are willing to incur significant transportation costs. As resumption of primary metal refining in this area seems improbable, future metallurgical demand is not anticipated.

In the past, chemical and industrial grade limes have been produced from the St. Paul Group in this area by selective quarrying of the purest beds. With modern large volume quarrying techniques there is no possibility that such products can be produced competitively from such occurrences.

The first crushed stone made in this part of the State was quarried in the St. Paul Group east of Harrisburg and the rocks have continued to be an important source of aggregate and related products. While there is no indication the physical qualities are notably different from the Beekmantown rocks, the St. Paul has enjoyed the advantage of being closest to the Harrisburg market. Hempt Brothers, Inc. currently operate a quarry near Paxtang for which the State Highway Department (Anon, 1961) provides the following information: Specific gravity 2.71, Percent absorption 0.24, and Daily tonnage 600. The same operators also have a 900 ton per day operation in somewhat higher beds of the St. Paul Group just over into Cumberland County which also supplies the Harrisburg area. The Pennsylvania Supply Company recently had a temporary operation removing a rock ridge on the south side of Routes Interstate 83 - US 322 somewhat southeast of Paxtang. This operation produced an acceptable aggregate from the upper (?) St. Paul Group of the thrust slice on the south side of that outcrop area.

Future development of aggregate production from the St. Paul Group in Dauphin County is largely limited by increasing urbanization. The best prospect for future development is the sizable block of undeveloped land lying between Route US 322 and the Rutherford Yards of the Reading Railroad. This location has several particular advantages in an urbanizing area. After completion of quarrying of a given block the hole is available for sanitary landfill. Cover fill is readily available from the weathered Martinsburg shales immediately south of the highway. The filled land is essentially as useful as the virgin land for an eastward extension of the industrial-commercial area that presently lies just west of the undeveloped block, and land useful for commercial development is also created south of the highway if the coverfill stripping is so conducted as to produce levelled areas. Another special situation that might warrant development is the bluff on the east side of Cameron Street between South Harrisburg and Steelton. The abandoned fluxstone quarries in this area have made tracts of flat land at the level of Cameron Street which have been used by a number of business establishments. Extension of these quarries might be practicable even under the restrictions imposed by working in so developed an area owing to the considerable increase in land value which could ensue from such an operation.

Annville Limestone

The Annville Limestone is well known as a source of good quality high-calcium limestone which enjoys a wide market for a number of applications which require such stone. The possibility of blending with the adjacent upper Ontelaunee Formation for controlled $MgCO_3$ content is discussed in consideration of Ontelaunee uscs. The analyses of Table 2 indicate that the quality of the stone remains fairly high throughout the county though it is presently being worked only at the extreme eastern edge of the county by the H. E. Millard Lime and Stone Company. Figure 25 shows the locations of the analyses given in Table 2 and gives indication of the areas of probable and possible available reserves.

The outstanding problem encountered in quarrying this rock is water flow in the quarries. The high value of the stone encourages deep pits and at the Annville Stone Company (later Michigan Limestone Company) property east of Hershey underground workings were extended below 400 feet before water flows reaching a maximum in excess of 10,000 gallons per minute forced abandonment (Foose, 1953). The last active quarry in the Swatara area was closed by sudden inundation. In the case of the Hershey mine attempts to keep water out of the workings seriously disturbed the ground-water regimen over a large area and led to considerable litigation with ground-water users and damage claims for sinkhole development.

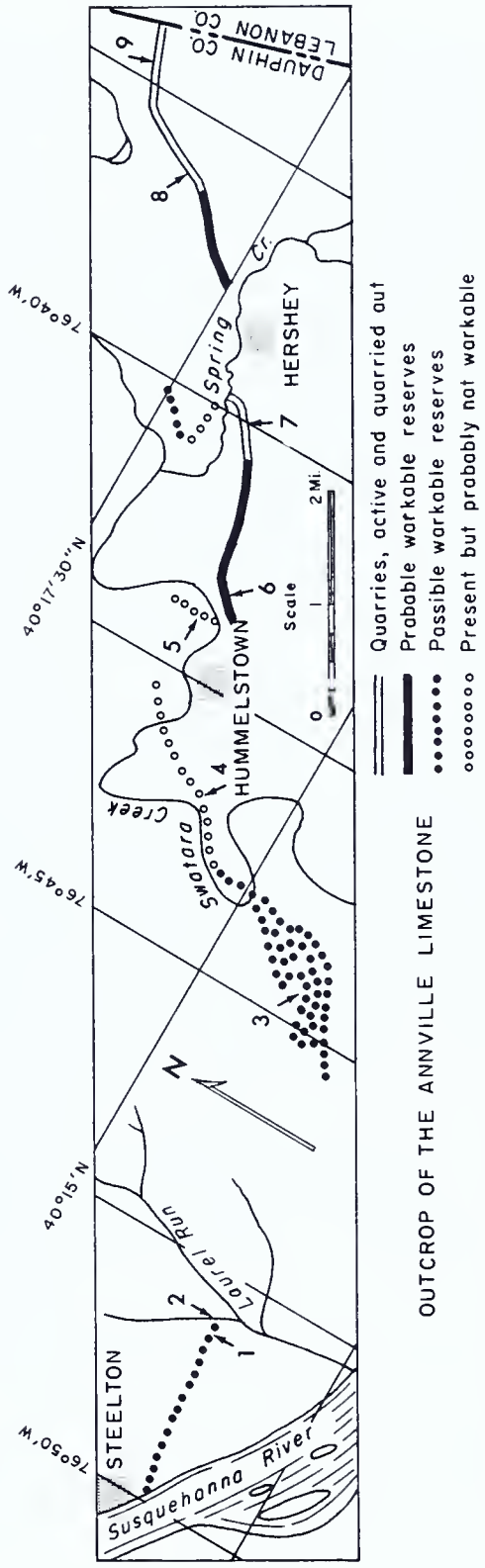


Figure 25. General economic distribution of the Annville Limestone in Dauphin County. Arrows and numbers show locations of chemical analyses reported in Table 2.

Myerstown Formation

It became apparent during the course of field work that rock from the Myerstown Formation has been used as road metal on township roads Generally, however, the formation is thin-bedded and breaks into platy fragments. Some of the beds are hard and tough giving rise to the characteristic ringing plates of the Myerstown float, but they occur with substantially softer and weaker interbeds. This type of rock will not yield crushed stone of a quality comparable to that readily available from the heavy-bedded limestones and dolomites lower in the section.

The analyses shown in Figure 24A indicate that parts of the Myerstown Formation might yield a satisfactory, though not notably pure, agstone; but the rock seems unsuitable for any other compositionally determined use. The physical properties of the rock are such that it might be more easily quarried in a straight agstone operation than the tougher heavy-bedded rocks lower in the sections; but, with present use and consumption patterns, it seems unlikely that agstone from this source could compete on the one hand with the high-grade limes produced from the pure rocks, and by-products of aggregate operations on the other hand.

Hershey Formation

The Hershey Formation has no potential value as the source of any mineral product for which there is a foreseeable demand. The Hershey lithology closely resembles that of the natural cement rock in the Jacksonburg Formation in the Lehigh cement district, but is too magnesian for the manufacture of cement. It is shaly, fissile, and strongly cleaved making it unsuitable for any physical use but simple fill. This last product is more easily obtained in the same immediate area from the weathered shale of the adjacent Martinsburg Formation.

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APPENDIX

MEASURED STRATIGRAPHIC SECTIONS

LOCALITY 1—LEMOYNE

Stratigraphy.—Hershey, "Oranda," and Mercersburg Formations.

Location and structure.—North side of Market Street, Lemoyne along the upper level of the Pennsylvania Railroad. Directly across Susquehanna River from Harrisburg at about lat. 40° 14½′ N, long. 76° 53′ W, northeast rectangle Lemoyne 7½-minute topographic quadrangle. The Martinsburg Formation is very contorted and strongly cleaved. It is separated from the Hershey Formation by a steep fault. The Hershey Formation dips quite steeply south but conspicuous foliation is cleavage parallel to the Martinsburg cleavage. The Hershey shows at least one high angle fault within the exposed thickness. A south-dipping thrust fault brings the overturned sequence of "Oranda" Formation and Mercersburg Formation over the Hershey Formation. Covered interval to south conceals thrust fault bringing Beekmantown Group up, probably against the Mercersburg Formation.

Remarks.—There is an unusually good exposure of the faults in this section clearly indicating lack of depositional continuity. The measurement of the "Oranda" and Mercersburg given here is by Prouty (1959).

	Thickness (Ft.)	
	Unit	*Cumulative*
Martinsburg Formation		
Unit		
1. Shale; dark gray, with occasional thin limestone layers, in many places pulled apart and brecciated, very contorted, prominent foliation is cleavage		
—fault—		
Hershey Formation, 65 ± ft.:		
2. Limestone; grayish-black, shaly and carbonaceous bedding in part obliterated by cleavage, at least one high angle fault within exposure, some purer limestone breccia fragments at fault with Martinsburg	65±	129.4±
—thrust fault—		
"Oranda" Formation, 49.8 ft.:		
3. Limestone; grayish-black, very finely crystalline to aphanitic, weathers brownish gray with thin dark shale partings, Basal 3.5 ft. mostly covered	9.5	64.4
4. Limestone; grayish-black, very fine-grained, thin platy beds, occasional thin dark shale partings	12.0	54.9

Unit		Thickness (Ft.) Unit	Cumulativ
5.	Limestone; dark-gray, finely carcarenitic, finely laminated, light yellowish gray weathering	7.0	42.9
6.	Limestone; dark-brownish-gray, fine-grained, thin dark shale partings	6.0	35.9
7.	Metabentonite (?); prominent break in exposure, mostly filled with surface wash	0.3	29.9
8.	Limestone; dark-gray, very fine-grained with numerous shale partings and occasional thin calcarenitic lenses, weathers yellowish gray	12.0	29.6
9.	Limestone; medium-dark-gray, thin calcarenites alternating with thin, fine-to-medium-crystalline beds, numerous dark shale laminae	3.0	17.6
10.	Limestone; trilobite-fragment calcarenite	0.6	14.6
Mercersburg (Upper Chambersburg) Formation, 14 ft.:			
11.	Limestone; dark-gray, very finely crystalline, about 2″ beds, nodular to slabby	8.0	14.0
12.	Limestone; medium-dark-gray, very finely crystalline, very thin, wavy, shaly partings, weathers medium light gray	6.0	6.0

Maximum probable concealed thickness of Mercersburg Formation (200′)

LOCALITY 2—LEMOYNE QUARRIES

Stratigraphy.—Partial section St. Paul Group.

Location and structure.—The youngest beds measured in detail lie at the southwest end of the abandoned quarry about 400 yards to the southeast of Interstate Highway 83 and directly west of the Pennsylvania Railroad tracks along the west bank of the Susquehanna River opposite Harrisburg. Underlying beds are exposed in the quarry wall to the northwest to about 100 feet from Highway 83. Northwest of the highway, exposure continues in cuts along the Pennsylvania Railroad and in the abandoned quarry now containing the Lemoyne sewage treatment plant directly northwest of the highway. Discontinuous exposure in the railway cuts extends northwestward about 650 yards to within about 100 yards of the Lemo interlock tower of the Pennsylvania Railroad, but the detailed section ends in the north quarry. The section is in the northeast corner of the Lemoyne 7½-minute topographic quadrangle at about lat. 40° 14¾′ N, long. 76° 53′ W.

Beds in the detailed section dip quite uniformly southeasterly at about 30° (maximum observed local variation 25°-40°) and are right side up. Underlying beds of the Beekmantown Group are apparently concordant and may be conformable though contact relations are obscure. Southeast of the quarry a few cuts along the railway and crops visible in the river bank at low water extend about 1850 yards to the vicinity of 6th St.,

New Cumberland. Exposure is insufficient to permit precise determination of the folded structure, and what additional thickness of strata may be represented is unknown.

Remarks.—Beds 1 to 92 in the section were measured by Prouty (1960). Beds 93-146 were described as transitional to the Beekmantown Group by Prouty and were not measured by him. The only lithic features in these beds apparently not represented higher in the section are the dark limestones, notably bed no. 106 and the others compared to it. Dolomite is not more abundant than at a number of levels higher in the section. Beds not described in detail but generally similar to those described, except for the apparent absence of further repetitions of the dark limestone (bed 106) lithology, continue to the Reading Railroad bridge, about 250 yards northwest of the highway, where they are followed by typical Beekmantown dolomites. Exposure in the immediate vicinity of the inferred contact is poor and contact relations are obscure.

The chemical analyses summarized in Figure 22B are from beds at least partially included in this section. It has proved impossible to associate particular analyses with particular beds of this section. The section described with the analyses, and its probable position in this section is discussed as Locality 2a.

Thicknesses of units not described in detail were computed from measurements on a map of about 1:7620 scale (1 cm=250′) prepared by projection from an aerial photograph on which the control points had been plotted. There is about 70 percent exposure in railway cuts in the generalized part of the section.

		Thickness (Ft.)	
		Unit	*Cumulative*
St. Paul Group (about 930 feet, no top)			
Covered at top (few exposures along railroad tracks in gentle folds).			
Unit			
1.	Limestone, dark, impure wavy partings, occasionally calcilutitic	15.0	1455.1
2.	Dolomite, massive, impure, gray	1.0	1440.1
3.	Limestone, dark, impure partings	2.8	1439.1
4.	Dolomite, massive, creamy weathering	1.5	1436.3
5.	Limestone, finely crystalline, dark, occasionally calcilutitic, one probable *Maclurites* gastropod	27.0	1434.8
6.	Dolomite, massive, gray, lensy	2.5	1407.8
7.	Limestone, dark finely crystalline, wavy clay partings	3.5	1405.3
8.	Calcilutite, dark, high calcium	6.5	1401.8
9.	Limestone, dark, wavy impure partings	6.0	1395.3
10.	Calcilutite, dark, high calcium	3.5	1389.3
11.	Limestone, dark-gray, finely crystalline, thin stylolitic laminae	7.5	1385.8

Unit		Thickness (Ft.) Unit	Cumulativ
12.	Dolomite, massive, creamy buff	4.0	1378.3
13.	Limestone, nearly aphanitic, very thin laminae	11.0	1374.3
14.	Limestone, very impure and dolomitic	1.2	1363.3
15.	Dolomite, massive, creamy buff, impure	5.5	1362.3
16.	Limestone, massive, high calcium, aphanitic	2.0	1356.8
17.	Limestone, highly impure anastamosing partings; fine limestone edgewise breccia lenses	2.0	1354.8
18.	Dolomite, gray, impure	0.3	1357.8
19.	Limestone, dark-gray, thin wavy impure partings	5.5	1352.5
20.	Dolomite, occasional limestone lenses	1.5	1347.0
21.	Limestone, dark-gray, thin wavy partings	4.7	1345.5
22.	Dolomite, thin limestone stringers	2.1	1340.8
23.	Limestone, dark-gray, finely crystalline; buff, impure dolomitic partings	6.4	1338.7
24.	Dolomite, creamy-buff	0.8	1332.3
25.	Limestone, dark-gray, finely crystalline; buff, impure dolomitic partings; probable *Maclurites* near base	4.8	1331.5
26.	Dolomite, buff-weathering, limy	4.0	1326.7
27.	Limestone, dark-gray, impure wavy dolomitic partings	5.3	1322.7
28.	Limestone, dark, finely crystalline; much black chert at 2 feet from base and upper 2 ft.	9.0	1317.4
29.	Dolomite, massive, dark-gray, silty; little black chert	8.0	1308.4
30.	Limestone, dolomitic; gray, finely crystalline, silty	8.5	1300.4
31.	Dolomite, massive, 1 to 2 inches relief at base	7.0	1271.9
32.	Calcisiltite, gray, dolomitic, fine cross-laminae, evidence on top and bottom not clear, black chert nodules near top	5.5	1284.9
33.	Calcilutite, light-brown, magnesian	3.2	1279.4
34.	Dolomite, massive	0.5	1276.2
35.	Calcilutite, stylolitic	1.5	1275.7
36.	Dolomite, massive	0.7	1274.2
37.	Calcilutite, massive, stylolitic; buff dolomitic clay splotches near top	2.1	1273.5
38.	Limestone, finely crystalline, impure dolomitic partings	5.5	1271.4
39.	Dolomite, massive, finely laminated	3.9	1265.9
40.	Limestone, dark-gray, finely crystalline; buff dolomitic splotches	4.0	1262.0
41.	Dolomite, massive	1.0	1258.0
42.	Limestone, gray, dove-weathering; bedded flint	6.0	1257.0
43.	Dolomite, impure, typical buff-weathering	0.5	1251.0
44.	Limestone, dark-gray, finely crystalline	0.8	1250.5
45.	Dolomite	0.4	1249.7
46.	Limestone, dark-gray; buff clay and silt bands	5.5	1249.3
47.	Dolomite, gray, typical buff-weathering	3.2	1243.8
48.	Calcilutite, dark, dove-weathering, conchoidal fracture	2.5	1240.6
49.	Dolomite, creamy-brown-weathering; few bluish-gray limestone chips throughout	0.8	1238.1

Unit	Thickness (Ft.) Unit	Cumulative
50. Limestone and dolomite mixed in irregular pattern; fragmented fossils	1.0	1237.3
51. Limestone, dark, very finely crystalline; impure buff dolomitic bands, black chert near base	7.0	1236.3
52. Dolomite, gray, highly impure, up to 1′ of relief at top	2.3	1229.3
53. Limestone, dark, finely crystalline	4.0	1227.0
54. Dolomite, limy, massive	1.3	1223.0
55. Limestone, very finely crystalline, speckled, silty weathered surface; black chert at top	2.0	1221.7
56. Limestone, dark-bluish-gray limestone chips giving brecciated appearance	2.0	1219.7
57. Dolomite, gray, typical buff-weathering; some bedded quartz	3.2	1217.7
58. Calcilutite, medium-gray; dove-weathering	0.8	1214.5
59. Dolomite gray, typical creamy-weathering	0.7	1213.7
60. Limestone, dark-bluish-gray; thin impure laminae; considerable dark and gray chert	6.0	1213.0
61. Dolomite, gray, buff-weathering and limestone, essentially calcilutite, in thin alterations	21.0	1207.0
62. Limestone, dark-gray, very finely crystalline, slightly mottled gray and light-gray surface	1.9	1186.0
63. Limestone, brownish-gray; dolomitic; 4″ bedded black flint near middle	1.2	1184.1
64. Dolomite medium-gray, finely laminated	5.7	1182.9
65. Calcilutite, medium-gray; fine hair-width impure laminae that give minute flow folds	0.8	1177.2
66. Dolomite, many hair joints throughout	0.4	1176.4
67. Limestone, dark-gray, thin impure dolomitic partings	7.6	1176.0
68. Dolomite, massive, creamy-weathering	1.1	1168.4
69. Limestone, dark-gray, nearly dense texture, weathering to slightly gray and light-gray mottled surface; thin dolomite bed in middle of unit	7.7	1167.3
Covered	13.0	1159.6
70. Dolomite, massively ledged though finely laminated	7.0	1146.6
71. Limestone, dark-gray, fine impure partings	1.1	1139.6
72. Limestone, dark-gray; very thin clay-silt partings, probable *Maclurites*	4.0	1138.5
73. Dolomite, massive, well-laminated	1.7	1134.5
74. Limestone, dark-gray, dove-weathering, very finely crystalline	1.2	1137.8
75. Dolomite, creamy-weathering; joints containing mineral dolomite	1.3	1131.6
76. Limestone, dark-gray, dolomitic silt and clay partings	9.8	1130.3
Covered	4.5	1120.5
77. Calcilutite, finely laminated, dove-weathering	5.0	1116.0
78. Dolomite, massive, partly covered	2.0	1111.0
79. Calcilutite, finely laminated, dove-colored	5.0	1109.0

Unit	Thickness (Ft.) Unit	Cumulative
80. Dolomite, massive, considerably jointed	3.0	1104.0
81. Calcilutite, chalky-weathered surface	4.0	1101.0
Covered	7.5	1097.0
82. Limestone, dark-bluish-gray (north side of south quarry)	1.0	1089.5
Covered	16.0	1088.5
83. Limestone, dark, impure dolomitic clay partings	5.5	1072.5
Covered	5.5	1067.0
84. Calcilutite, medium-gray, dove-weathering	9.0	1061.5
Covered (under Interstate Highway 83)	115.0	1052.5
85. Limestone bluish-gray, irregular clay mottled; *Tetradium syringoporoides, Lephospira* sp. in calcilutite interlayers	11.0	937.5
86. Dolomite, massive, creamy-buff-weathering	1.0	926.5
Covered	12.0	925.5
87. Dolomite, massive, creamy-weathering	3.0	909.5
88. Limestone, dark-gray; thin wavy stylolitic partings	2.0	906.5
89. Dolomite, massive, creamy-buff-weathering	0.8	904.5
90. Limestone, dark-gray, light-gray weathering, stylolitic	1.7	903.7
91. Limestone, thin beds alternating with about equal 0.5 to 1 inch silty and clayey dolomitic bands to give striped appearance: the latter occasionally penetrate former to yield isolated limestone "pebbles," giving the appearance of conglomerate; unidentified low-spired gastropods	2.5	902.0
92. Dolomite	3.1	899.5
93. Limestone: dolomite-mottled, gradational to no. 92	1.8	896.7
94. Limestone: coarse clastic texture, dolomite-mottled	0.8	894.9
95. Limestone: laminated	1.8	894.1
96. Limestone: magnesian	0.8	892.3
97. Limestone: irregularly laminated, fairly pure	3.4	891.5
98. Dolomite	1.8	888.1
99. Dolomite	3.3	886.3
100. Limestone: magnesian, finely laminated	1.0	883.0
101. Limestone (?): very-dark, structureless	0.2	882.0
102. Limestone: coarse magnesian laminae	2.2	881.8
103. Limestone: like no. 102 at top, gradationally becomes mottled toward base, gradational to 104	3.0	879.6
104. Dolomite: gradational to 103, stylolitic basal contact	0.7	876.6
105. Dolomite: faintly laminated, 4 beds with stylolitic partings	3.5	875.9
106. Limestone: dark-weathering, coarsely laminated and occasionally mottled with impure dolomitic seams	14.3	872.4
107. Dolomite	1.3	858.1
108. Limestone: laminated, especially toward top	3.4	856.8
109. Limestone: magnesian, laminated, ¼″ dark shaly parting at base, dark-weathering	4.0	853.4

Unit	Thickness (Ft.) Unit	Cumulative
110. Dolomite	1.2	849.4
111. Limestone: similar to no. 108	3.9	848.2
112. Limestone: similar to no. 109	1.8	844.3
113. Limestone: pure	0.3-0.4	842.5
114. Dolomite: stylolitic base	1.3-1.4	842.1
115. Limestone: similar to 108	3.0	840.8
116. Dolomite: stylolitic at base	0.4-0.5	837.8
117. Limestone: dolomite-laminated, gradational to dolomite at top	1.9	837.4
118. Limestone: like no. 117, dolomitic laminae increase upward	3.8	838.5
119. Limestone: dark-weathering like 106	5.8	831.7
120. Dolomite: 3 beds	2.7	825.9
121. Limestone: impure laminae concentrated in several zones	7.3	823.2
122. Limestone: magnesian, finely laminated, 3 beds	0.7	815.9
123. Limestone: irregularly laminated	3.7	815.2
124. Limestone: magnesian, finely laminated, coarser grained than 122	0.7	811.5
125. Limestone: irregular impure dolomitic laminae, fragmental zone in center of bed	1.7	810.8
126. Limestone: dark weathering like 106	4.2	809.1
127. Dolomite	1.5	804.9
128. Dolomite: distinctly laminated	0.4	803.4
129. Limestone: pure	1.3	803.0
130. Limestone: calcarenitic	0.2	801.7
131. Limestone: laminated, dark	0.4	801.5
132. Limestone: dolomitic-mottled	5.1	801.1
133. Limestone: highly magnesian, laminated	2.7	796.0
134. Limestone: irregularly laminated	2.2	793.3
135. Dolomite	1.3	791.1
136. Limestone: irregularly dolomitic-mottled, grades to dolomite at top	3.1	789.8
137. Limestone: faintly laminated, magnesian at base (?)	2.5	786.7
138. Dolomite: relict limestone beds up to 1″	1.5	784.2
139. Limestone: pure	2.2	782.7
140. Dolomite	1.4-1.5	780.5
141. Limestone: irregular impure laminae, strongly slickensided lower bedding plane well exposed (near base of exposure in northwest corner of quarry)	4.1	779.1
Not measured in detail—partly covered, limestones and dolomites as before, lowest strata probably included in St. Paul Group in Dauphin County calculated thickness about	250	775
Beekmantown Group (upper part) (about 525′ exposed)		
Pinesburg Station Dolomite (?)		
Heavy bedded dolomites with less than 10% limestone interbeds about	250	525

Unit	Thickness (Ft.) Unit	Cumulative
Rockdale Run Formation (upper part)		
Heavy interbeds, about 70% dolomite, laminated clastic limestone interbeds and limy zones about 30% of section	about 275	275
Covered to Chambersburg Limestone exposure of Locality 1 (thrust contact)		

LOCALITY 2a—LEMOYNE QUARRIES

Stratigraphy.—Partial Section, St. Paul Group.

Location.—The beds in this section are included in the section described as locality 2. Lower part of this section apparently lies within the long covered interval under Interstate Highway 83 in that section.

Remarks.—This section has been compiled from the sampling descriptions reported by Lesley (1879) for the series of bed-by-bed chemical analyses graphically summarized in Figure 23B. The lithic names described are derived from the analysis according to Figure 17. Bed numbers are the same as those given by Lesley (1879), which may be consulted for the full analyses. A tabular summary of the analyses for $CaCO_3$, $MgCO_3$, and insoluble residue is given by Miller (1934, p. 342).

This section is mentioned in a number of reports on limestone in Cumberland County, but the only nearly precise location is given by Lesley (1892) who locates the beginning (north end) of the exposure at a lime kiln in the quarry about ½ mile south of the (Pennsylvania) railroad bridge (p. 324-325). Examination of the 1906 edition of the New Cumberland 15-minute quadrangle shows several structures presumably associated with quarry operations in this area which now lie under the South Bridge approaches. No evidence can be found of the old kiln which was presumably covered during the highway construction.

In an effort to match the analyses given by Lesley with beds described in the preceding section, 1-inch to 10-foot strip logs were prepared from both descriptions. No reasonable approximation of coincidence could be obtained by comparing the two logs. The only control on positioning that seems fairly certain is that the two beds described by Lesley as cherty (5 and 24) must lie within the 140-foot zone of chert-bearing beds (28 to 63 inclusive) of the previous section. On this basis at least 93 feet of the lower part of this section lie in the long covered interval of the previous section. A correlation more plausible than most that could be arranged equates Lesley's bed 115 to Prouty's bed 85, which just neatly bridges the covered interval. No correlation, however, permits establishment of reasonable bed-for-bed equivalence through the whole column.

	Thickness			
	Unit		Cumulative	
	ft.	in.	ft.	in.
t. Paul Group				
Unit				
1. Pure dolomite, medium-light-gray with a few calcite veins	3	0	370	4
2. Dolomite, light-gray, crystalline secondary calcite	2	9	367	4
3a. Limestone, dark-gray, crystalline with irregular calcite splotches				
3b. Limestone, dark-gray, with abundant quartz silt laminae gradational to above without bedding plane	3	6	364	7
4. Pure limestone, medium-gray, slight calcite veining	4	6	361	1
5. High-calcium limestone, dark-gray, finely crystalline with occasional calcite veins and chert nodules	8	1	356	7
6. High-calcium limestone, dark-gray mottled, laminated, a few calcite veins	1	0	348	6
7. Limestone, medium-gray, finely crystalline with thin silt laminae	1	0	347	6
8. Limestone, light-gray mottled, faintly laminated; a few calcite veins	0	9	346	6
9. High-magnesian limestone, light gray, abundant thin calcite veins	2	3	345	9
10. Pure limestone, dark-gray, crystalline, with a few small calcite blebs	2	8	343	6
11. High-calcium limestone, medium-gray, finely crystalline with abundant calcite blebs	3	8	340	10
12. Pure high-magnesian limestone, medium-gray mottled, faintly laminated, calcite veins	5	7	337	2
13. High-calcium limestone, light-gray, faint lamination, obliterated updip by recrystallization	3	8	331	7
14. Pure limestone, pinkish-gray, finely crystalline	12	8	327	11
15. Pure limestone, medium-light-gray, vaughnitic, fairly pure	4	4	315	3
16. High-calcium limestone, medium-dark-gray, fine-grained	2	9	310	11
17. Dolomite, light-gray, calcite veins (note 1)	2	8	308	2
18. Pure limestone, medium-gray, laminated	1	0	305	6
19. Pure dolomite, medium-light-gray, some calcite veins	1	1	304	6
20. High-calcium limestone, medium-dark-gray, laminated	2	0	303	5
21. Pure high-magnesian limestone, medium-gray crystalline, fine calcite veins	1	2	301	5
22. Pure limestone, medium-gray, calcite veins	2	0	300	3
23. Dolomite, light-gray, abundant calcite veins	1	4	298	3

Unit		Thickness Unit ft.	in.	Cumulative ft.	in.
24.	Pure limestone, very dark-gray, numerous small chert nodules, some calcite veins	6	11	296	11
25.	High-magnesian limestone, light-gray, numerous calcite veins	0	7	290	0
26.	Limestone, medium-gray, variable silt content	0	9	289	5
27.	High-magnesian limestone, finely crystalline, a few calcite and quartz veins	1	11	288	8
28.	Limestone, dark-gray, crystalline	6	5	286	9
29.	Dolomite, light-gray, crystalline, calcite and quartz veins	4	1	280	4
30.	High-calcium limestone, dark-gray, faintly laminated in part, some small calcite blebs	2	7	276	3
31.	Dolomite, medium-gray, massive calcite veins	1	0	273	8
32.	High-calcium limestone, medium-dark-gray, massive	3	0	272	8
33.	Magnesian limestone, medium-dark-gray, massive	0	2	269	8
34.	High-magnesian limestone, medium-dark-gray, crystalline	0	10	262	10
35.	Pure magnesian limestone, medium-dark-gray	0	9	262	0
36.	Pure limestone, medium-dark-gray	0	10	261	3
37.	Pure magnesian limestone, medium-gray	0	4	260	5
38.	Pure limestone, dark-gray	4	6	260	1
39.	Dolomite, light-gray, calcite veins	0	10	255	7
40.	High-calcium limestone, dark-gray mottled	4	2	254	9
41.	Dolomite, light-gray, abundant quartz and calcite veins	3	2	250	7
42.	Pure limestone, light-gray	1	2	247	5
43.	High-magnesian limestone, medium-gray, a few calcite veins	2	3	246	3
44.	High-calcium limestone, dark-gray, calcite blebs	0	3	244	0
45.	Pure limestone, medium-gray	3	6	243	9
46.	Dolomite, light-gray, a few calcite veins	0	10	240	3
47.	Pure limestone, medium-gray	0	5	239	5
48.	Dolomite, light-gray, calcite veins	0	2	239	0
49.	Dolomite, same as 48	0	6	238	10
50.	Pure limestone, dark-gray	1	10	238	4
51.	Dolomite, light-gray, calcite veins	4	0	236	6
52.	Limestone, medium-dark-gray, some calcite veins	0	5	232	6
53.	High-calcium limestone, medium-dark-gray	5	2	232	1
54.	Magnesian limestone, medium-dark-gray, calcite veins	0	11	226	11
55.	High-magnesian limestone, medium-dark-gray, calcite veins	1	0	226	0
56.	Limestone, dark-gray, calcite veins and some quartz	1	10	225	0
57.	Dolomite, medium-gray, locally large calcite veins	2	0	223	2
58.	High-calcium limestone, medium-gray	1	10	221	2

Unit		Thickness Unit ft.	in.	Cumulative ft.	in.
59.	Pure high-magnesian limestone, light-gray, numerous calcite blebs	0	10	219	4
60.	Limestone, medium-gray	2	4	218	6
61.	Dolomite, medium-gray, large calcite veins	1	10	216	2
62.	High-magnesian limestone, medium-gray	1	11	214	4
63.	Magnesian limestone, medium-gray	1	11	212	5
64.	High-magnesian limestone, medium-dark-gray	3	2	210	6
65.	Magnesian limestone, medium-dark-gray	3	2	207	4
66.	Dolomite, medium-light-gray, thin calcite veins	1	9	204	2
67.	Pure limestone, medium-gray, faintly laminated	14	0	202	5
68.	Dolomite, medium-dark-gray, calcite and quartz veins	2	10	188	5
69.	High-calcium limestone, dark-gray	6	6	185	7
70.	Dolomite, medium-dark, calcite veins and splotches	3	8	179	1
71.	High-calcium limestone, dark-gray	4	6	175	5
72.	Pure limestone, dark-gray	5	6	170	11
73.	High-calcium limestone, medium-gray, quite pure	3	7	165	5
74.	Limestone, dark-gray	5	0	161	10
75.	High-magnesian limestone, medium-dark-gray, quartz and calcite veins	2	3	156	10
76.	Pure limestone, dark-gray, quartz and calcite veins	1	2	154	7
77.	Dolomite, medium-gray, quartz and calcite veins	2	3	153	5
78.	Limestone, dark-gray	3	10	151	2
79.	Limestone, dark-gray, faintly laminated	6	0	147	4
80.	Dolomite, light-gray, calcite veins	2	7	141	4
81.	Limestone, medium-gray	2	8	138	9
82.	Pure limestone, medium-gray	1	9	136	1
83.	High-magnesian limestone, medium-gray	6	3	134	4
84.	Pure limestone, light-brownish-gray to medium-gray (note 2)	7	3	128	1
85.	High-calcium limestone, dark-gray	6	8	120	10
86.	Siliceous dolomite, medium-gray, calcite veins	11	5	114	2
87.	High-calcium limestone, brownish-gray, vaughnitic	2	5	102	9
88.	Dolomite, light-olive-gray, some veins	5	9	100	4
89.	High-calcium limestone, light-gray, vaughnitic	0	8	94	7
90.	Pure high-magnesian limestone, light-gray, finely crystalline	0	9	93	11
91.	High-calcium limestone, dark-gray	2	5	93	2
92.	Dolomite, very light-gray, calcite veins	1	11	90	9
93.	Limestone, medium-dark-gray	2	0	88	10
94.	Dolomite, medium-gray, calcite veins	4	0	86	10
95.	High-calcium limestone, dark-gray, quite pure	8	0	82	10
96.	Magnesian limestone, dark-gray	0	8	74	10
97.	Dolomite, light-gray, calcite veins	10	6	74	2
98.	High-calcium limestone, dark-gray	3	0	63	8
99.	Dolomite, light-gray, calcite veins	1	8	60	8
100.	High-calcium limestone, medium-dark-gray	1	4	59	0

Unit		Thickness Unit ft.	in.	Cumulative ft.	in.
101.	Dolomite, very light-gray, calcite veins	5	6	57	8
102.	Pure limestone, medium-dark-gray	0	11	52	2
103.	Magnesian limestone, medium-gray, calcite veins	4	6	51	3
104.	High-calcium limestone, medium-dark-gray	2	3	46	9
105.	Dolomite, very light-gray, calcite veins	0	10	44	6
106.	High-calcium limestone, medium-dark-gray	1	9	43	8
107.	Dolomite, very light-gray, calcite veins	4	10	41	11
108.	Limestone, medium-dark-gray, local calcite veins	2	0	37	1
109.	High-magnesian limestone, medium-dark-gray	3	0	35	1
110.	Pure limestone, medium-dark-gray	5	6	32	1
111.	Dolomite, medium-dark-gray, calcite veins	1	7	26	7
112.	Limestone, medium-dark-gray	5	6	25	0
113.	Dolomite, light-gray, calcite veins	5	6	19	6
114.	High-calcium limestone, medium-dark-gray	14	0	14	0

Notes

1. Analysis for lower end of bed 17 is high-calcium limestone. The lithic description is typical of dolomites in this sequence and quite unlike any of the other high-calcium limestones. Hence I infer that the upper analysis is essentially correct for the bed and that the sample for the lower part was in some way misidentified during collection or analysis.
2. An apparent typographic error appears in the published analysis for the lower end of bed 84. The published value of insoluble residue is 8.640 which gives a total analysis of almost 107% (not tabulated) which is a much larger deviation from 100 than in any other analysis totaled. It seems probable that this is a misprint for 3.640 which would give a more reasonable total analysis, and the latter value is used in Fig. 23B.

LOCALITY 3—STEELTON

Stratigraphy.—Myerstown, Annville, and Epler Formations.

Location and structure.—Section is measured in and to the north of the large limestone quarry operated by the Bethlehem Steel Company on the south side of Steelton Borough at about lat. 40° 13′ N, long. 76° 49′ W in the north-central rectangle of the Steelton 7½-minute topographic quadrangle.

The partial section of the Epler Formation is exposed across the width of the main quarry opening. The section given here was measured by Prouty (in Gates, 1960), and the exact line of traverse is not reported. The beds dip southerly at 26° to 55° and are overturned. Several thrust faults parallel to the mean bedding may be observed in the quarry.

The thrust contact of the Epler and the Annville Formations may be observed at the east end of an older cut lying on the north side of the main quarry at its western end (See illustration Figure 15). An indefinite

portion of both contacting formations as well as the entire intervening Ontelaunee Formation is absent in this rather complex zone, which is essentially parallel to the mean bedding. The Annville Formation has two main tectonically defined benches with complex internal structure. The measured thickness is that of benches, which fairly reflects the present thickness of the formation in this structural situation; but it will be obvious by consideration of Figure 16 that a significantly greater depositional thickness of beds must be represented. It is inferred that the individual contorted beds as well as the general stratigraphic sequence are overturned.

The thrust contact between the Annville and Myerstown Formations is exposed at several places along the north wall of the old cut west of the Annville exposure. The Myerstown Formation is discontinuously exposed, and was originally measured by Prouty (1959) along an alley (Good Street) which has been subsequently obliterated by a public housing project. In view of the usually large thickness of Myerstown recorded here and the inordinately large 234-foot interval between metabentonite horizons, repetition of strata, probably by thrusting, is to be suspected in the thick interval (unit 4 of section) but could not be definitely recognized even in extensive temporary exposure provided during the construction project. The highest unit in the measured section approximately corresponds with the top of the formation as shown in temporary exposure (see Remarks) where it is found in imbricate thrust contact with the Martinsburg Formation. The overall dip is about 35° to 40° southerly, overturned, with considerable variation and local reversals.

Remarks.—Prouty's original descriptions of this section show an additional 30-foot covered interval in the Myerstown Formation and indicate more than 300 feet of Hershey Formation above the Myerstown in presumable stratigraphic continuity. This interpretation was hard to reconcile with the pattern of Hershey distribution that emerged in mapping across Dauphin County, but poor exposure through the critical part of the section made it difficult to resolve the question until extensive temporary exposures were made during construction. It was initially apparent that the major part of the upper Hershey Formation as identified by Prouty was calcareous shales of the type found at Fiddler's Elbow (Locality 5) which it was concluded should properly be assigned to the Martinsburg Formation, and that some noncalcareous shale of probable Martinsburg affinity occurred below the supposed Hershey conglomerates. The significance of the latter fact, however, became apparent only when an excavation up to 20 feet deep was cut across the contact area. It was then shown that the main body of Myerstown was in thrust contact with a 20-foot slice of Martinsburg in turn thrust on 10 feet of Myerstown

thrust on about 10 feet of shale overlying a thinner and discontinuous limestone slice followed by the main body of shale. It is thus evident that the covered interval recorded at the top of Prouty's Myerstown section approximately corresponds to the structurally highest shale slice in the imbricate thrust zone while the "Hershey conglomerate" zone, which is somewhat broken and more poorly exposed in an older road nearby used in the original section, actually represents the lower Myerstown slice.

A phyllitic bed bearing fairly abundant highly deformed graptolites was found within the Martinsburg portion of the imbricate zone. This probably represents the source of "Hershey" graptolites reported by Prouty at this section.

	Thickness (Ft.)	
	Unit	*Cumulative*
Covered		
Myerstown Formation (354.5 max. exposed)		
1. Limestone, bluish-gray, slabby-weathering, crinoidal, with rough travertine surface	1.0	998.1
2. Metabentonite zone, buffish, gray clay and alternating chippy, buff shale	1.5	997.1
3. Limestone, blue-gray, crinoidal, compact, slabby	10.0	995.6
4. Limestone, same, largely covered, probably too thick owing to repetition	178.5 max.	985.6
5. Limestone, thin-bedded, slabby-weathering, dark-blue to nearly black, fine-to medium-crystalline	43.0	807.1
6. Limestone, dark-bluish-gray, medium-to coarse-crystalline, massively ledged	1.0	764.1
7. Metabentonite zone, gray, buffish-weathering intermixed with buff, chippy shale, highly schistose locally due to slaty cleavage	2.0	763.1
8. Limestone, dark-grayish-blue, finely crystalline, with some coarsely crystalline beds, slabby-weathering	5.0	761.1
9. Covered, columnar quartz float in soil	26.0	756.1
10. Limestone, dark-blue, slabby, mostly covered	18.0	730.1
11. Covered	31.0	712.1
12. Limestone, dark, thin-bedded to shaly, slickensided, at foot wall of large Bethlehem Steel quarry Thrust fault, displacement uncertain	37.5	681.1
Annville Limestone (28.5 ft.)		
13. Limestone, medium-bluish-gray, with occasional fine, light-gray to white laminae; crushed and faulted zone near middle, displacement questionable Thrust fault within Annville Formation	18.5	643.6
14. Limestone, blue and light-gray mottled, high-calcium, massively ledged Thrust fault, large displacement	10.0	625.1

Unit	Thickness (Ft.) Unit	Cumulative
Epler Formation, partial section (615.1 ft.)		
15. Limestone, medium-dark-gray, fine-grained, slightly laminated, 2 thrust faults included in this interval	48	615.1
16. Limestone, aphanitic, high-calcium, bluish-gray and white mottled, laminated	11	567.1
17. Limestone, dark-gray, clayey	34.0	556.1
18. Limestone, dark-bluish-gray, finely crystalline	8.0	522.1
19. Limestone, white, finely crystalline, laminated	2.5	514.1
20. Dolomite, limy, dark-gray, fine- to medium-crystalline, weathers brownish gray	10.5	511.6
21. Dolomite, limy, weathers into fine chips	6.0	501.1
22. Dolomite, limy, dark on fresh and weathered surfaces, chippy-weathering	15.0	495.1
23. Dolomite, massively ledged	9.0	480.1
24. Limestone, light to white, somewhat mottled with gray; variable crystal size	14.0	471.1
25. Dolomite, limy, light-bluish-gray	7.0	457.1
26. Limestone, dark-gray, fine-to medium- crystalline	5.0	450.1
27. Dolomite, limy, light-bluish-gray	7.0	445.1
28. Limestone, dark-gray	1.2	438.1
29. Dolomite, light-bluish-gray, mottled	0.8	436.9
30. Limestone, dark-gray	2.5	436.1
31. Dolomite, light-bluish-gray, mottled	6.0	433.6
32. Limestone, dark-gray, smoky-gray weathering	2.0	427.6
33. Dolomite, light-blue-gray, mottled	6.0	425.6
34. Limestone, dark-gray, massively ledged	12.0	419.6
35. Dolomite, light-bluish-gray, mottled	1.6	407.6
36. Limestone, dark-gray, smoky-gray weathering, lower 9 feet compact, lightly fractured into blocks; little bedded black chert; small, white quartz "rosettes" in upper third	47.0	406.0
37. Limestone, dark-bluish-gray, fine-to medium-crystalline	6.0	359.0
38. Limestone, dark, finely laminated	11.0	353.0
39. Covered	7.0	342.0
40. Limestone, dark-to medium-gray, massively ledged, fine-laminated	37.0	335.0
41. Dolomite, light-bluish-gray	9.0	298.0
42. Limestone, fine-to medium-crystalline, finely laminated with buff-weathering impure partings; stylolitic bedding common, also slickensided bedding laminae	80.0	289.0
43. Dolomite, limy, weathers to mealy, granular surface	7.0	209.0
44. Limestone, medium-crystalline, dark-gray; contains a "boudinage" of dolomite several feet in width at 18 feet from the base	61.0	202.0
45. Covered	6.0	141.0
46. Dolomite, limy, light-bluish-gray	9.0	135.0
47. Limestone, dark, laminated with dark impure partings	9.0	126.0
48. Dolomite, limy, bluish-gray; hackly fracture	12.0	117.0

Unit		Thickness (Ft.) Unit	Cumulative
49.	Limestone, dark, fine-grained; considerable thin impure laminae	9.0	105.0
50.	Limestone, dark-gray, fine-to medium-crystalline	12.0	96.0
51.	Limestone, bluish-gray, including a 0.5-foot white bed near base; black chert in thin beds, near top	17.0	84.0
52.	Covered	21.0	67.0
53.	Limestone, dark, fine-grained, weathering differentially along fine laminae to give a fluted surface	6.0	46.0
54.	Limestone, dark, fine-grained, mottled with different shades of gray	9.0	40.0
55.	Covered	21.0	31.0
56.	Limestone, bluish-gray, medium-crystalline considerable white quartz	10.0	10.0
	Covered below		

Note: A wide covered zone representing a questionable thickness of rock separates the main quarry from a small abandoned quarry to the south. In the latter and adjacent to the highway directly west, about 75 feet of gray to light-gray limestone occurs before the Triassic fault contact.

LOCALITY 4—RUTHERFORD YARDS, READING RAILROAD

Stratigraphy.—Partial section (short), St. Paul Group.

Location and structure.—About 195 feet of almost complete exposure interrupted by minor faults starts 85 feet west of the vehicular overpass on the south side of the southernmost track by the Rutherford Yards of the Reading Railroad, about lat. 40° 16′ N, long. 76° 46′ W, SE rectangle of Harrisburg East 7½-minute topographic quadrangle. Beds dip 15° to 28° southeast, apparently right side up.

Remarks.—Rocks exposed here are typical of much of the St. Paul lithology as mapped in Dauphin County but do not include the uniformly light-gray-weathering limestone beds which are quite similar to the Annville limestone.

Unit		Thickness Unit ft.	in.	Cumulative ft.	in.
St. Paul Group					
	Covered				
1.	Limestone, medium-dark-gray, fine-grained, massive when fresh; weathers medium light gray (80%) with olive-gray silty-textured laminae 1/16″ to 3/8″.	15+		54	8+
2.	Limestone, medium-dark-gray, fine-grained, distinct shaly laminae, mostly thin but reach ½″, becomes silty in lower half, small calcarenite lenses. Weathers light gray with dark-brownish-gray shaly laminae and medium-gray silty laminae	2	3	39	8

Unit	Thickness Unit ft.	Thickness Unit in.	Thickness Cumulative ft.	Thickness Cumulative in.
3. Limestone, medium-dark-gray, fine-grained, massive when fresh; weathers medium light gray (75%) with numerous thin olive-gray-weathering shaly laminae.	1	9	37	5
4. Magnesian limestone, medium-gray, finely crystalline, 0 to 2″ of dark-brownish-gray chert 4″ from base, weathers yellowish gray with distinct laminae.	1	10	35	8
5. Limestone, medium-dark-gray, mostly finely crystalline with medium-crystalline patches, weathers medium light gray with very sparse thin brownish-gray shale laminae near top becoming more abundant toward the base which approaches the character of unit 1.	10	6	33	10
6a. Dolomite, medium-light-gray, fine-to medium-crystalline, abundant quartz veins, weathers light olive gray to grayish yellow.	2+			
Slump block, conceals fault (?), dolomite first exposed to west thought to be same as to east.				
6b. Dolomite, medium-light-gray, fine-to medium-crystalline, highly fractured and quartz veined, in part largely replaced by quartz boxwork, thickness variable perhaps as result of tectonic necking, weathers light olive gray to grayish yellow.	2	9±	23	4
7. Limestone, medium-gray, finely crystalline, with small blebs and lenses of coarsely crystalline white calcite, weathers light gray with a few thin brownish-gray shaly laminae.	3	0	20	7
8. Limestone, medium-dark-gray, finely crystalline, massive where fresh, weathers predominantly medium light gray to light olive gray with yellowish brown silty laminae which become more abundant downward and pass into a mottled lithology about ⅔ light gray, ⅓ yellowish-brown weathering.	9	1	17	7
9. Dolomite, medium-dark-gray, fine-to medium-crystalline, ½″ to 1″ shale parting 5½″ from top, weathers dusky yellow.	1	4	8	6
Fault—covered interval, units 7, 8, and 9 again exposed to west above unit 10.				
10. Limestone, medium-dark-gray, fine-grained, very faintly laminated where fresh, weathers medium light gray with some irregular light-olive-gray 1/16″ to 1/4″ silty laminae. Dark-brownish-gray nodular chert horizon at base.	7	2	7	2
Covered.				

LOCALITY 5—FIDDLER'S ELBOW

Stratigraphy.—Martinsburg Formation (partial section), Myerstown Formation, Annville Formation, Ontelaunee Formation (partial section—upper).

Location and structure.—Section is well exposed except in one covered interval along the south side of Swatara Creek near the covered bridge on Fiddler's Elbow Road about 2 miles southwest of Hummelstown Square at about lat. 40° 14′ 55″ N, long. 76° 44′ 10″ W in the northwest rectangle of the Middletown 7½-minute topographic quadrangle. The section starts in the Martinsburg Formation about where the H. T. Power line crosses the creek and runs southeasterly along the abandoned canal cut to the junction of a small tributary stream. The section continues easterly from this point mostly under cover to the east side of Fiddler's Elbow Road where small patches of conglomerate are found. Continuing eastward fair exposure of the Myerstown Formation is found in the slope above the road south of the secondary crushing and screening plant of the George Ebersole and Sons property. From this point the section is offset northward along the Annville-Myerstown contact to the opening behind the primary crusher. From here eastward the Annville Formation is exposed to the entrance of the main quarry which is largely developed in the Ontelaunee Formation. Additional exposure of the Ontelaunee Formation is found east of the quarry in a continuation of the abandoned canal cut along Swatara Creek.

The beds in the section generally have a somewhat variable southeast dip and are overturned. There are a number of small thrust faults visible within the section, and at least two of the formational contacts are thrust with an indefinite thickness of beds missing thereby. The thrusts dip southeasterly and are apparently about parallel to the mean bedding.

Remarks.—Units 2, 3, and 4 of the description were referred to the Hershey Formation by Prouty (1959) and unfortunately proposed for the type section of this unit. Integration of this section into detailed mapping of the County shows that the lithology of unit 2 cannot be differentiated from a number of exposures of undisputed Martinsburg Formation which are not certainly restricted to its base. Furthermore, lithic equivalents of unit 2 do not occur in the Hershey as mapped in Lebanon County (Geyer and others, 1958, 1963; Gray and others, 1958). This mapping demonstrated the validity of the Hershey as a mappable unit and Prouty's paper was intended to provide a formal definition of the unit mapped. The integrity of the Hershey Formation as a mappable unit is destroyed by inclusion of the unit 2 lithology which seems properly referable to the Martinsburg as developed in this area. Prouty's inclusion of this unit in

:he Hershey seems to have been based entirely on the subordinate car-
ɔonate content which has not been found a useful mapping criterion. Based upon abundant normal Martinsburg float through most of the thick covered interval (unit 3), an assignment of this interval to the Martinsburg Formation, with the possible exception of a small thickness of calcareous rock at the west end, is the obvious conclusion if unit 2 is recognized as Martinsburg. If Prouty's identification of unit 2 were accepted, his interpretation is logical but somewhat difficult to reconcile with the distribution and character of the float.

The significance of the conglomerate unit is problematic. An exposure present at the time Prouty examined the section has since been covered by development of the crushed stone plant. The single remaining exposure in the cut east of North Union Street is of poor quality but sufficient to indicate that the unit is not continuous and is apparently separated from the Myerstown Formation by some shale. The carbonate fragments appear to be somewhat rounded in part and give the suggestion of true clasts but the possibility that this occurrence may be a fault breccia is not excluded. The probable attitude of this feature appears to be discordant, hence not conformable, to the nearby Myerstown Formation. In the absence of clear evidence the unit is very tentatively assigned to the Hershey Formation but its presence is inconsistent with all other data concerning the distribution of the Hershey conglomerate member.

Units 5 to 9 of this section comprise the type section of the Myerstown Formation (Prouty, 1959). The cut subsequently made for the primary crusher at the Ebersole quarry clearly exposes a thrust at the Myerstown-Annville contact parallel to the mean bedding but discordant to local structures, especially in the Myerstown Formation. It is the present author's opinion that structural discordance across the poorly exposed Hershey (conglomerate member)-Myerstown contact suggests a similar thrust at this contact also. The section contains very little of the dense, platy limestone which characterizes much of the Myerstown Formation in Lebanon County; and no metabentonite (?) beds are present. On the basis of other Myerstown Formation sections in Dauphin and Lebanon Counties and the newly available structural data, it would appear that approximately the lower half and possibly part of the uppermost beds of the formation are tectonically absent in this section.

Martinsburg Formation	*Thickness (Ft.)*	
Unit	*Unit*	*Cumulative*
1. Shale, very dark-gray, weathers olive gray, mostly noncalcareous.		
2. Shale, very dark-gray, weathers olive gray, in part slightly calcareous with some thin interbeds of		

Unit		Thickness (Ft.) Unit	Cumulativ
	medium-dark-gray calcareous quartz siltite and quartzose calcisiltite. Total carbonate estimated as less than 10%.	300.0	695.6
3.	Covered interval. Includes a few thin ledges of medium-bedded, medium-gray, silty limestone near top and a little dark-gray shaly limestone float near base which might represent a small thickness of the true Hershey Formation. However, abundant float southwest of the intersection extending all the way to North Union St. is typical Martinsburg shale.	135.0	395.6
Hershey Formation (?)			
4.	Conglomerate, angular to subrounded dolomite pebbles and cobbles in a very dark-gray calcareous shale matrix poorly exposed at one point near westernmost crop of the Myerstown Formation, formerly exposed at another point.	0 to 4.0	260.6
	Contact, concealed fault (?), there is some indication of a thin repetition of shale between conglomerate and the Myerstown Formation.		
Myerstown Formation (56′)			
5.	Limestone, shaly; alternating with black, fissile, carbonaceous shale.	18.0	256.6
6.	Limestone, dark-gray, thin-bedded, slabby, shows "fluting" on weathered surface.	12.0	238.6
7.	Limestone, dark-gray, thin-bedded, slabby.	13.0	226.6
8.	Limestone, shaly, carbonaceous, some white, columnar quartz along bedding.	3.0	213.6
9.	Limestone, dark-gray, thin laminate, weathering into the rock along some laminae gives distinctive type of "fluting"; some columnar quartz.	10.0	210.6
	Thrust		
Annville Limestone (77.6)			
10.	Limestone, dark-gray, few thin carbonaceous layers.	7.5	200.6
11.	Limestone, gray, showing lighter gray "frosted" appearance on fresh fracture, high-calcium.	7.0	193.1
12.	Limestone, bluish-white and bluish-gray striped.	2.0	186.1
13.	Limestone, gray and bluish-gray, mottled, high-calcium.	3.0	184.1
14.	Limestone, dark-blue.	6.0	181.1
15.	Limestone, dark-blue with irregular, impure gray bands.	12.5	175.1
16.	Limestone, bluish-gray, finely crystalline.	11.1	162.6
17.	Limestone, light-gray with blue bands.	2.8	151.5

Unit		Thickness (Ft.) Unit	Cumulative
18.	Limestone, dark-blue, finely crystalline.	2.5	148.7
19.	Limestone, bluish-white and blue-striped, occasionally mottled, highly "fluted" on weathering.	5.0	146.2
20.	Limestone, dark-blue, finely crystalline.	3.2	141.2
21.	Limestone, medium-gray and medium-light mottled, finely crystalline, high-calcium.	5.0	138.0
22.	Limestone, very light-gray and medium-striped, dense, high-calcium.	6.0	133.0
23.	Limestone, light-gray dense, high-calcium.	0.5	127.0
24.	Limestone, very light-gray with dark-gray aphanitic, weathered surface shows "fluting" with few thin laminae weathering into rock rather than standing out in relief as is commonly the case.	3.5	126.5
	Thrust contact with Beekmantown dolomite is sharp showing drag of overlying dolomite beds near top of west quarry face.		
	Stratigraphic displacement unknown.		
Beekmantown Group			
	Ontelaunee Formation (Partial section 123′)		
25.	Dolomite, medium-gray to medium-dark-gray, very finely to finely megacrystalline, deeply weathered medium light gray, parting into 1- to 6- foot layers; fresh blocks in quarry medium dark gray and dark gray; thin layers of carbonaceous shale common.	40.0	123.0
26.	Limestone, medium-gray, very finely megacrystalline, scattered nodules of black chert.	0.5	83.0
27.	Dolomite, poorly exposed, medium-gray, very finely megacrystalline, weathering very light gray.	30.0	82.5
28.	Dolomite, medium-gray to medium-light-gray, very finely, megacrystalline, microcrystalline in part; partings not recorded.	32.0	52.5
29.	Limestone, medium-light-gray, with dark-gray streaks, very finely megacrystalline; imperfect bedding cleavage.	0.5	20.5
30.	Dolomite (parting not recorded) and several limestone interbeds, poorly exposed; dolomite, medium-gray to medium-light-gray, very finely megacrystalline; several elongate dark chert nodules in limestone beds.	20.0	20.0
	Additional beds of Ontelaunee Formation exposed to east along creek.		

LOCALITY 6—NORTH SIDE HUMMELSTOWN, PENNSYLVANIA

Location and structure of section.—Rock is exposed in northeast face of Pennsylvania Supply Corp. quarry on north bank of Swatara Creek 0.35 mile north of center square in Hummelstown, Dauphin County, Pennsylvania, in Hummelstown quadrange at approximately 2.20 miles east of long. 76° 45′ and 1.45 miles north of lat. 40° 15′.

Bedding strikes N 70° W and dips 25° SW overturned. Several shattered zones with slickensided blocks of dolomite are visible in the northern corner of the quarry. Prominent vertical fault strikes N 5° E; direction of slickensides indicates strike-slip movement.

Section measurement by Prouty (1963) begins at fault on northeastern face and continues southeastward along the face to end of exposure. Cherty bed near top of exposures may be western extension of cherty zone in Ontelaunee dolomite of Lebanon and Berks Counties. All thickness measurements made with an 8-foot tape.

	Thickness (Ft.) Unit	Cumulative
Annville Limestone		
No measurable exposures. Believed to be less than 75 feet thick (Geyer, pers. comm.).		
Beekmantown Group		
Ontelaunee Formation		
Exposures in trench dug for pipeline; medium-dark-gray, megacrystalline dolomite.		
Estimated thickness of exposure.	25	606½
Concealed. Traverse on aerial photo, 1050 feet about S 20° W; bedding strikes N 70° W and dips 30° SW overturned.	525	581½
Fault		
Unit		
1. Dolomite, medium-light-gray, microcrystalline to very finely megacrystalline.	7	56½
2. Dolomite, medium-light-gray, finely to medium megacrystalline.	1	49½
3. Dolomite, medium-light-gray, very finely megacrystalline, parting into poorly developed 2-foot layers; well-developed joints and irregular fractures.	7½	48½
4. Dolomite, medium-gray, very finely megacrystalline.	12	41
5. Dolomite, medium-gray, very finely megacrystalline; regular parallel laminae	1½	29
6. Dolomite, medium-light-gray, very finely megacrystalline, weathering light yellowish gray, parting 5½ feet above the base; indistinct laminae; 6-inch zone of fault breccia adjacent to fault surface; fault strikes N 80° W and dips 30° SW; direction of slickensides indicates oblique movement along fault.	8½	27½

Unit	Thickness (Ft.) Unit	Cumulative
7. Dolomite, medium-gray, very finely megacrystalline, weathering yellowish-gray, regular parallel laminae.	1½	19
8. Dolomite, medium-gray, very finely megacrystalline, weathering yellowish gray, parting into 1½ foot layers; stylolitic partings in upper 2 feet.	7	17½
9. Cherty dolomite layer, dark-gray, tends to split into 1-inch beds; tightly packed ostracode shells; varies in thickness from 3 inches to 1 foot.	1	10½
10. Dolomite, medium-gray, very finely megacrystalline, weathering yellowish gray, parting into 1- to 3½-foot layers.	9½	9½
Exposed thickness of Ontelaunee Formation		81½
Total Estimated thickness of Ontelaunee Formation		606½

LOCALITY 7—EAST SIDE, HUMMELSTOWN, PA.

Stratigraphy.—Upper Part of Epler Formation.

Location and structure of section.—Section No. 23 is located along traffic circle on U. S. Route 422, ¼ mile south of Hummelstown, Dauphin County, Pennsylvania in the southwestern part of Hummelstown quadrangle at approximately 0.85 mile north of lat. 45° 15′ and 2.2 miles west of long. 76° 40′. Upper 100 feet or so of beds are exposed north of quarry across highway to the northeast.

Beds strike N 25° E and dip 25° SE overturned. Overturning implied on basis of order of superposition with the younger Ontelaunee dolomite outcropping to the northwest and structurally underlying Epler limestone. Section originally described by Hobson (1963).

	Thickness (Ft.) Unit	Cumulative
Lower Ordovician Series		
Beekmantown Group		
Ontelaunee Dolomite		
Unit		
1. Unmeasured exposures of dolomite on both sides of Reading Company's railroad tracks and in field to south of tracks.	not measured	
Epler Formation		
2. Concealed to uppermost exposures in quarry. Estimated 100 to 200 stratigraphic feet.	150	431
3. Limestone, medium-gray, calcarenitic, parting into thin irregular beds; irregular dolomitic and siliceous		

Unit	Thickness (Ft.) Unit	Cumulative
laminae; several dolomitized, low-inspired, dextrally coiled gastropods on bedding surface.	100	281
Following exposures in road cut southwest of quarry.		
4. Limestone, alternating medium-gray to medium-light-gray, roughly fracturing, cryptogranular with several smoothly fracturing beds, parting into regular 2-inch to 1-foot layers; lenses and thin beds of pelmatozoan calcarenitic very common; dark, siliceous laminae in most beds; section described in detail but summarized here owing to rather uniform lithology.	181	181
Measured thickness of Epler Formation		431
Concealed to Triassic beds	not measured	

LOCALITY 8—SWATARA QUARRIES

Stratigraphy.—Myerstown and Annville Formations.

Location and Structure.—Section measured in the abandoned quarries of the Swatara area on the west side of Hershey. Annville Formation section is best exposed and was measured by Prouty (1959) at the west end of the westernmost quarry (approximately 40° 16′ 45″ N, 76° 40′ 12″ E). The best Myerstown exposure is found east of State Route 340 running northwesterly from the northwest corner of the large central quarry (approximately 40° 16′ 50″ N, 76° 40′ 05″ E). Both exposures are in the south-central rectangle of the Hummelstown 7½-minute topographic quadrangle.

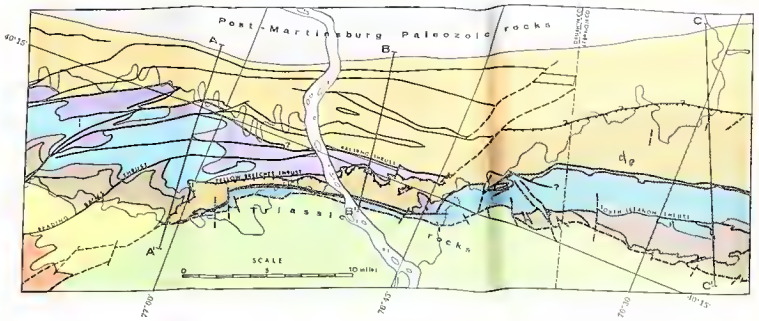
Dips in this part of the quarry area range from 55° to 80° southeasterly and are overturned. Through most of the measured section of the Myerstown Formation northwest of the quarries the dip averages about 60° northwesterly and is apparently overturned more than 180°. The hinge line is covered and may well be faulted. The contact with the Martinsburg Formation is evident only in float. The nearest Martinsburg outcrops show southeasterly dips.

Martinsburg Formation Unit	Thickness (Ft.) Unit	Cumulative
1. Dusky-yellow-weathered phyllite with orange-brown silt laminae exposed in cut west of section.		
2. Shale, slightly calcareous where fresh, medium-gray, weathers grayish yellow. Exposed as float only.		
Hershey Formation ? (less than 20′)		
3. Limestone, very shaly, thinly parted, medium-gray, weathers grayish yellow; exposed as float only.	less than 20	

Unit	Thickness (Ft.) Unit	Cumulative
Myerstown Formation (max. probable 216.2′)		
4. Limestone, float fragments, thin-bedded, medium-dark-gray, finely crystalline, weathers medium light gray.	max. about 90	355.7
5. Limestone, thin- to medium-bedded, medium-dark-gray, finely crystalline, weathers medium light gray with a few thin dark shale laminae.	1.9	265.7
6. Partly covered, scattered ledges similar to 5	27.3	263.8
7. Limestone, thin- to occasionally medium-bedded, medium-dark-gray, finely crystalline, weathers medium light gray with some thin dark shale partings.	10.0	236.5
8. Limestone, medium-gray, fossil-fragment calcarenite with abundant small (less than 4mm) pelmatazoan plates, with interbeds like unit 7.	2.7	226.5
9. Limestone, essentially identical to unit 7.	36.7	223.8
Covered	max. 47.6	187.1
10. Limestone, very dark-gray, impure, with numerous carbonaceous films and slickensided surfaces. *Prasopora* and brachiopod fragments in this horizon in footwall of westernmost quarry	6.5	139.5
Annville Limestone (133.0 ft.)		
11. Calcarenite, dark-blue to black- and gray-speckled, coarse-grained, massive-ledged; limestone breccia, grains up to ½ in. in diameter.	7.0	133.0
12. Limestone, dark-gray, shaly, laminated, carbonaceous.	2.0	126.0
13. Calcarenite, dark-gray, medium- to coarse-grained, massive ledged.	1.5	124.0
14. Limestone, dark-gray to black, slightly impure, carbonaceous; columnar quartz float.	20.0	122.5
15. Limestone, light- to medium-gray, high-calcium, fine-grained, fractures with "frosted" bluish-gray appearance.	12.0	102.5
16. Limestone, medium-bluish-gray, almost white on weathered surface; suggestion of fossil fragments near middle; columnar quartz float.	43.0	90.5
17. Covered interval.	8.0	47.5
18. Limestone, bluish-gray, laminae differentially eroded to give "fluted" appearance; fine-grained.	11.0	39.5
19. Covered interval.	10.0	28.5
20. Limestone, medium-gray, slightly magnesian, massive-ledged.	3.5	18.5
21. Limestone, dark-gray-and medium-gray-mottled, high-calcium, thinly laminated and fluted, fine-grained, weathers medium to light gray.	15.0	15.0
Ontelaunee Formation.		

Unit		Thickness Unit ft.	Thickness Unit in.	Thickness Cumulative ft.	Thickness Cumulative in.
22.	Limestone, medium-gray, cryptogranular; medium-light-gray lobes and lenses of dolomite.	3	0	734	5
23.	Dolomite, medium-dark-gray, very finely megacrystalline, parting into 1- to 2-foot layers; laminated in part; layers of carbonaceous shale.	20	5	731	5
24.	Dolomite, medium-light-gray, very finely megacrystalline, weathering yellowish grey, parting into 4-inch to 1-foot layers; regular parallel laminae.	6	0	711	0
25.	Dolomite, medium-dark-gray, very finely megacrystalline, weathering light gray.	1	0	705	0
	Covered: very sparse float in soil predominantly medium-to medium-dark-gray, finely crystalline dolomite; some light- and medium-gray limestone.	600	0	704	0
26.	Dolomite, medium-dark- to medium-gray, finely crystalline, faintly laminated on weathered surface, heavy bedded, some beds with 1″ to 4″ partings. Includes medium-dark-gray limestone intervals.	25	0	104	0
27.	Mostly covered: includes medium-dark-gray limestone, weathering medium light gray.	10	0	79	0
	Covered: abundant float, mostly medium-dark-gray, fine- to medium-crystalline dolomite includes sparse dark-brownish-gray chert fragments.	23	0	69	0
	Covered: float as before but no chert.	46	0	46	0
Base of Ontelaunee Formation as mapped, typical Epler limestone float 250′ southeast.					

TECTONIC SKETCH MAP OF CENTRAL GREAT VALLEY



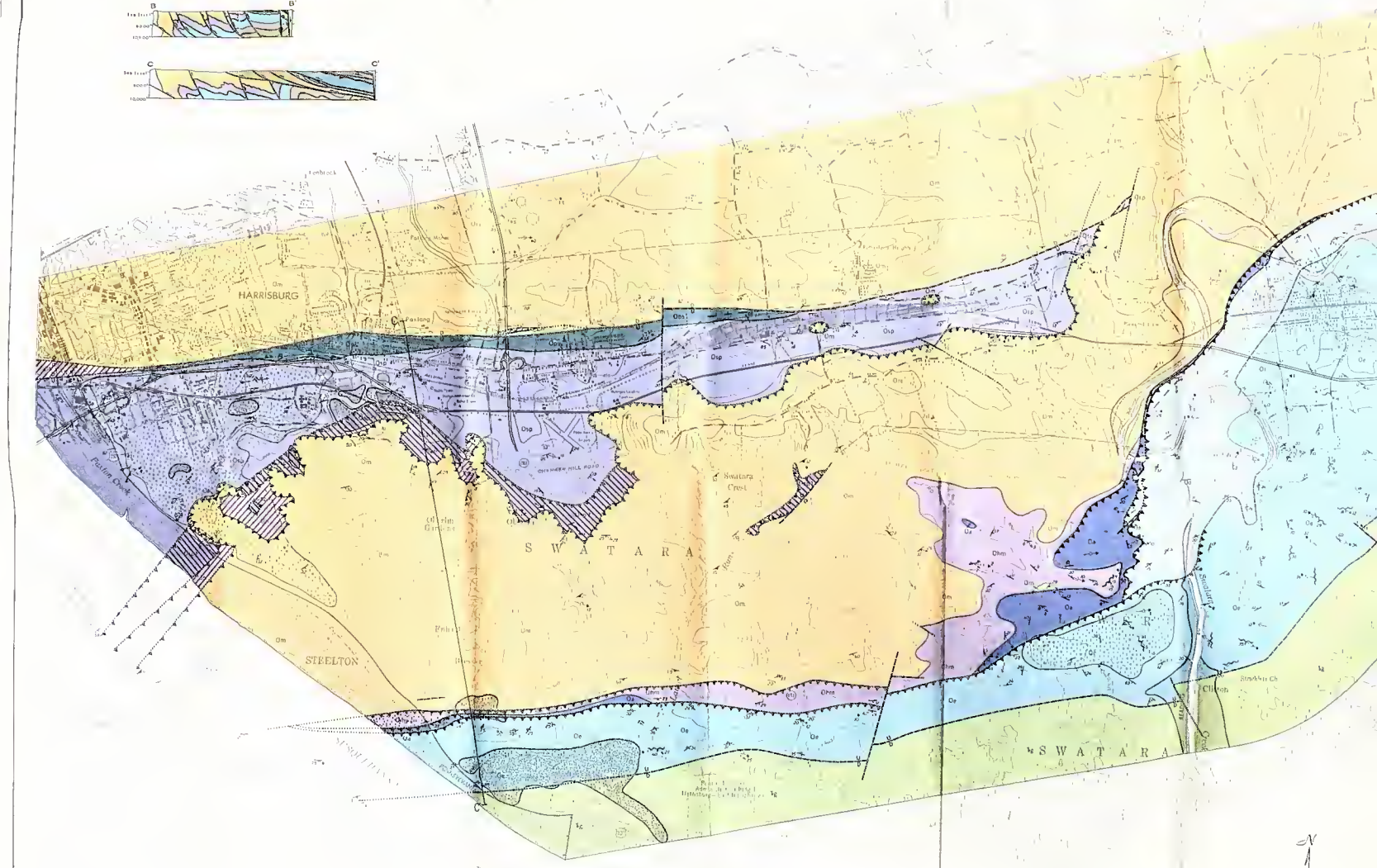
KEY TO TECTONIC MAP AND SECTIONS

- Middle and Upper Ordovician Martinsburg Formation
- Middle Ordovician limestones
- Lower Ordovician Beekmantown Group
- Upper Cambrian Conococheague Group
- Middle Cambrian Elbrook and Buffalo Springs Formations
- Lower Cambrian, mostly clastics and Tomstown Dolomite
- Precambrian volcanics

Cross hatch on preprint indicates allochthonous rocks of Tulpehocken Valley syncline. Area without overprint includes autochthonous rocks of Cumberland Valley synclinorium with exception of inadequately known probable allochthonous slivers within the Martinsburg Formation

- Tellus Beeches thrust
- Other thrust faults
- Normal faults and tear faults

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY



Base from Army Map Service Harrisburg East, Hummelstown, and Palmyra 7½-minute quadrangles and U. S. Geological Survey Steelton and Middletown preliminary 7½-minute quadrangles

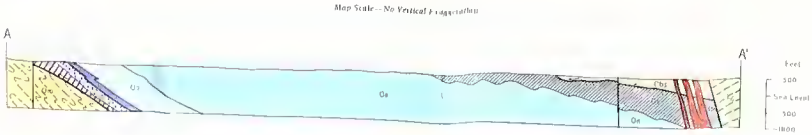
N

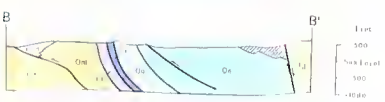
SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGIC CROSS SECTIONS

Map Scale—No Vertical Exaggeration

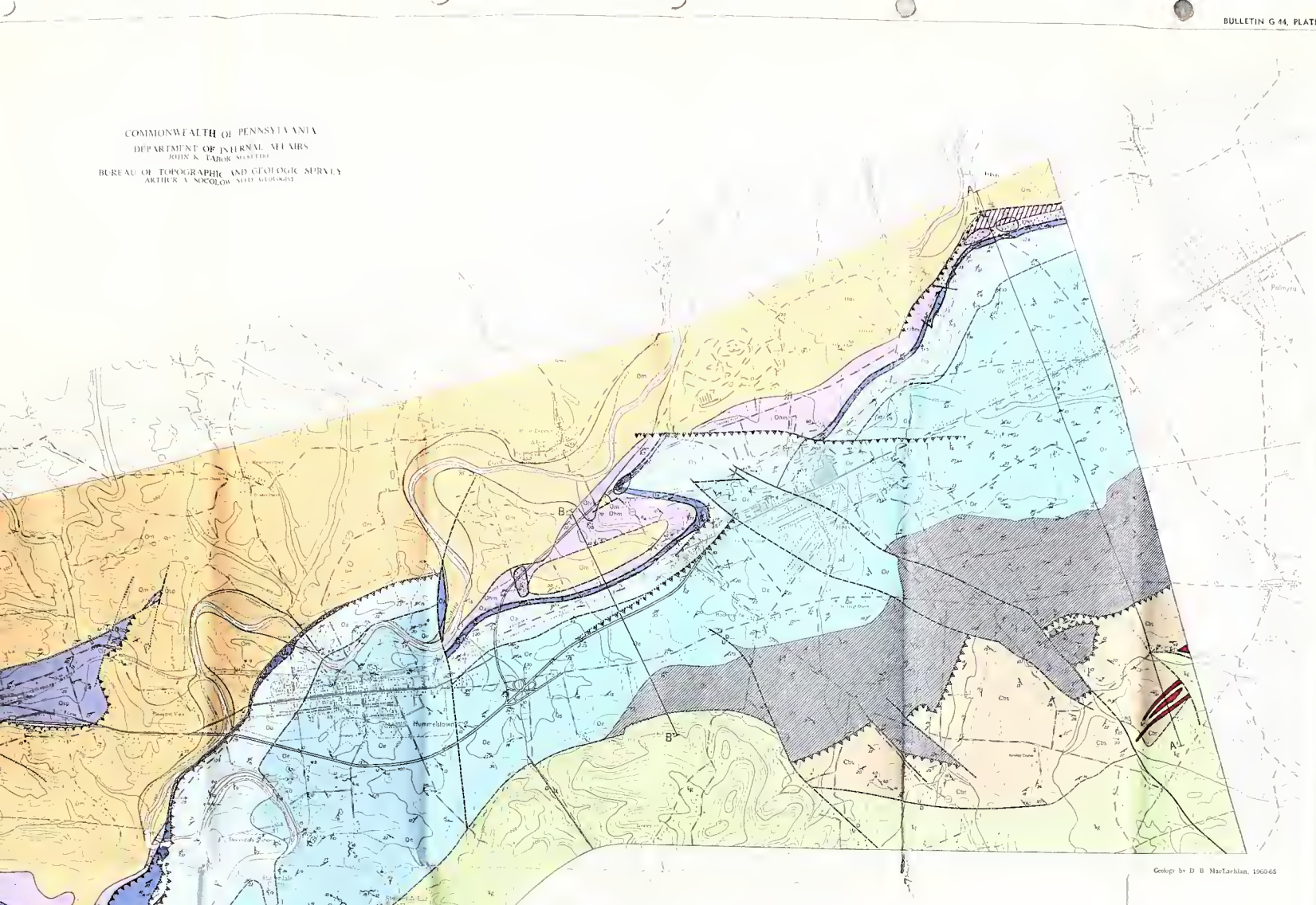




GEOLOGIC MAP OF THE CAMBRO-ORDOVICIAN CA
OF DAUPHIN COUNTY, PENNSYLVANIA

1967

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF INTERNAL AFFAIRS
JOHN K. TABOR, SECRETARY
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
ARTHUR A. SOCOLOW, STATE GEOLOGIST



Geology by D. B. MacLachlan, 1960-65

SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

GEOLOGIC MAP OF THE CAMBRO-ORDOVICIAN CARBONATES OF DAUPHIN COUNTY, PENNSYLVANIA

1967

EXPLANATION

SURFICIAL MATERIALS

Shown only where bedrock is substantially obscured, no attempt is made to show maximum extent of these deposits

- Artificial fill, sanitary fill, slag and spoil piles
- Modern alluvial deposits of major streams
- Older gravelly silts of higher terraces

BEDROCK

TRIASSIC

- Diabase dikes
- Gettysburg Formation

ORDOVICIAN

CUMBERLAND VALLEY SEQUENCE

- Om — Myerstown Formation
- Probable upper St. Paul Group in thrust slice
- Osp — St. Paul Group
- Ops — Pinesburg Station Formation

LEBANON VALLEY SEQUENCE

- Om — Martinsburg Formation
- Hershey Formation
- Ohm — Hershey Myerstown undifferentiated
- Myerstown Formation
- Ox — Annville Formation

Beekmantown Group

- Oo — Ontelaunee Formation
- Oe — Epler Formation
- Stonehenge Formation

Rocks of Hain and Stonehenge formations of the Beekmantown Group not exposed

CAMBRIAN

UPPER CAMBRIAN CUT OUT BY THRUST FAULT

- Cbs — Buffalo Springs Formation

SYMBOLS

CONTACTS

- Definite contact
- Inferred contact
- Concealed contact

MISCELLANEOUS SYMBOLS

- Active quarry
- Abandoned quarry—larger openings only

STRUCTURAL SYMBOLS

- Strike and dip of beds known to be right side up
- Strike and dip of beds where it is not known which side is up.
- Horizontal beds
- Strike of vertical beds
- Strike and dip of overturned beds
- Strike and dip of beds rotated more than 180°
- Generalized strike of folded beds showing plunge of foli axes
- Generalized strike and dip of crumpled, plicated, crenulated, or undulating beds
- Strike and dip of cleavage
- Horizontal cleavage
- Strike and dip of definite second generation cleavage
- High angle fault—U, up, D, down. Arrow shows dip where known
- Fault showing relative movement
- Thrust, barbs on side of upper plate
- Thrust, known extent limited to single exposure, barbs on upper plate
- Trend of linear lineation developed on bedding plane
- Strike and plunge of minor fold showing degree of plunge
- Horizontal fold axis
- Strike and plunge of recumbent minor fold
- Axis of anticline
- Axis of syncline
- Strike and dip of foliation in phyllite, slate, and shale, may be bedding, cleavage, or both